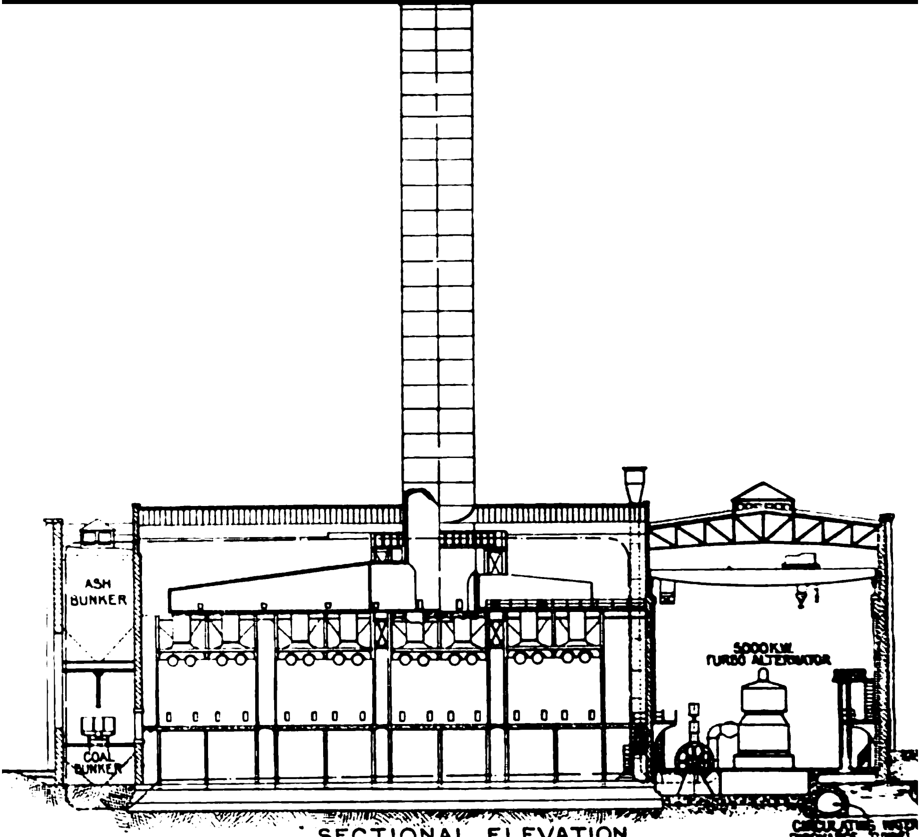

Proceedings

Institution of Electrical Engineers, Society of Telegraph Engineers, Society of Telegraph Engineers and ...

H. Vinton Hayes.

JOURNAL

OF THE

INSTITUTION OF ELECTRICAL ENGINEERS,

INCLUDING

ORIGINAL COMMUNICATIONS ON TELEGRAPHY AND ELECTRICAL SCIENCE.

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The Institution is not, as a body, responsible for the opinions expressed by individual authors or speakers.

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* At a Meeting of the Birmingham Local Section, held December 16, 1903.

Obituary Notices :—

JOURNAL

OF THE

Institution of Electrical Engineers.

Founded 1871. *Incorporated* 1883.

VOL. 33.	1903.	NO. 164.

The Three Hundred and Ninety-sixth Ordinary General Meeting of the Institution was held at the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, November 12, 1903—Mr. ROBERT KAYE GRAY, President, in the chair.

The minutes of the Annual General Meeting of May 28, 1903, were taken as read, and signed by the President.

The names of new candidates for election into the Institution were announced, and it was ordered that they should be suspended in the Library.

The following list of transfers was published as having been approved by the Council :—

From the class of Associate Members to that of Members—

Joseph Norman Bulkley.	Carl A. L. Prusmann.
F. W. E. Jones.	David Evan Roberts.

From the class of Associates to that of Members—

G. M. Carr.	S. Paterson.
A. H. Dumaresq, Capt. R.E.	Charles Newton Russell.

From the class of Foreign Members to that of Members—

R. J. Reidy.

From the class of Associates to that of Associate Members—

Lionel E. Buckell.	James Lowson.
W. M. Carver.	David E. McLaren.
W. J. Cooper.	F. J. Moffett.
W. Drysdale.	H. J. Moysey.
G. S. Flood.	T. H. Parker.
C. C. Garrard.	S. Payne.
John Angus Hay.	W. Riley.
Richard J. M. Holmes.	E. L. Rossiter.
J.H. Johnson.	Kenneth Watson.

H. G. Whiting.

From the class of Students to that of Associates—

Mahomed Ahsan.
Frederick Vernon Harrap.
Bernard Gustave Jones.
Edwin Lewis Monk.
Jas. Alfred Troughton.
Francis Noel Younger.

Donations to the *Library* were announced as having been received since the last meeting from Messrs. C. W. Barnes, H. Bashforth, British Fire Prevention Committee, Constable & Co., Crosby, Lockwood & Son, Engineering Standards Committee, J. J. Fahie, E. Guarini, Harper Brothers, Director-General of Indian Telegraphs, W. P. Maycock, C. Naud, Oerlikon Maschinenfabrik, R. Oldenbourg, Patent Office, A. Pollak, W. B. Sayers, J. Swinburne, Whittaker & Co., and H. Williams; to the *Building Fund* from Messrs. T. Cushing, F. H. Goodall, J. Kynoch, J. O. McLaren, J. MacLean, W. H. Patchell, C. Silver, Major A. M. Stuart, F. H. Webb, Finsbury Technical College Engineering Society; and to the *Benevolent Fund* from Messrs. J. W. Fletcher, R. T. Glazebrook, A. E. Levin, W. H. Patchell, M. Robinson, Semenza Presentation Fund, C. Silver, H. J. Wagg, and F. H. Webb, to all of whom the thanks of the meeting were duly accorded.

The PRESIDENT announced a provisional list of papers for reading at General Meetings up to the end of the year.

The Premiums referred to in the Annual Report of the Council adopted in May, 1903, were then presented by Mr. James Swinburne, the late President.

INAUGURAL ADDRESS.

By ROBERT KAYE GRAY, President.

Gentlemen, another session has opened, and another President addresses you, the twenty-eighth person who has had this privilege. On this occasion one of our usual forms of procedure must be dispensed with, or I should have to fill the rôle of vacating the chair in my own favour. You will remember that Mr. Swinburne, who gave us an extremely interesting and valuable address a year ago, resigned the Presidentship two months before his term was completed. This he did in order to permit a telegraph man to be at the head of the Institution during the recent International Conference in London, to which Telegraph Delegates from foreign Governments were invited.

For obvious reasons I cannot criticise Mr. Swinburne's action in this matter, but I feel at full liberty to say that the manner in which he carried out what he thought to be the best interests of the Institution was accomplished with great consideration, and for this, so far as it affected me personally I tender him my sincerest thanks.

You, gentlemen, have placed me in the honourable position that I now fill, but the honour which you have conferred is one that carries with it a responsibility which might better have been confided to other hands.

The Institution is ever growing, and shows the life that dwells in every healthy hardy plant which from a seedling becomes a well-grown tree. Not one of the founders of the Institution in 1871 could have foreseen the developments of a third of a century later. The guidance of your former Presidents and Councils has been wise, and it is for us to follow in their footsteps with the same open minds which have led to the consolidation of many diverging interests into one complete whole. We are under a debt of gratitude to the Institution of Civil Engineers for many advantages they have conferred on us, and not the least is the cordial hospitality they give us in their magnificent building. Your successive Councils have continually had brought to their notice the desirability of our Institution possessing a permanent habitation, and it is believed this feeling is general among the members. I take this opportunity of stating that in deference to this view a site has been acquired, which in the opinion of the Council's technical advisers will amply suffice for the erection of an Institution building in which a suitable lecture theatre and other necessary offices could find place. Your Council has no intention of proceeding with the construction of the Institution building until they believe the Institution to be strong enough financially to meet the necessary expenditure while remaining in possession of a handsome surplus. It is also thought that developments in the near future may permit of an alliance with kindred institutions for the erection of one large Temple of Engineering, where the various branches may find their homes. A portion of this building could be allotted to the joint occupation of the different sections of engineering, and each section could in addition possess the accommodation it might require for its own particular work; a Senate or Court of Governors appointed by the sections being constituted the supreme body. I understand that the late Sir William Siemens had such a conception, and perhaps its realisation may now be within the range of practical politics. In the event of such a scheme maturing, the property in Tothill Street, which the Institution has acquired, can be sold, as it will always be a realisable asset so long as no special building is erected on it. A Temple of Engineering costing a quarter of a million would be a fit home for the engineering bodies of this country.

Many opinions have been advanced as to the scope and aim of an Institution such as ours: as to what it should do and what it should not do, and as to its relations with kindred societies. This, of course, is contentious matter, and should not probably be touched in an address, but I take advantage of the immunity from criticism in this room which my position to-day grants me, and will make a few remarks on the subject. In early days the Institution was the only Association or body which could voice the views of electrical men, and therefore everything touching their interests was fit matter for discussion. To-day the necessity is not so imperative, as, owing to the great development of the electrical industry, other bodies are springing up who can more properly deal with a variety of questions which affect, but only indirectly affect the institution as an Institution of Electrical Engineers. As time goes on, this necessity will become less and less, and the

Institution will fall back into its proper function as an Institution of Electrical Engineers, and will not fill the part of an Association of Electrical Engineers, which it has often been obliged to do in the past. The word "Institution" in this connection bears in my mind the meaning of a body for dealing with technical interests, while "Association" implies a corporation whose functions are related to everything affecting general interests. I hope that the Institution, for some time yet, will continue to take an interest in things general as well as technical, and conserving the open mind and progressive spirit, to which I referred in my preceding remarks, will assist in every reasonable way the aspirations of the different electrical associations which are being formed from day to day. These associations must not be looked upon as rival or interfering bodies, but rather as bodies formed to meet a real want, and from that point of view deserving every assistance and encouragement from the older body. There is one more point in this connection which from time to time provokes comment and criticism, and that is that many members of this Institution contribute papers to the Institution of Civil Engineers and other bodies which, in the opinion of the critics, should have been presented to this Institution. I do not think this is a fair or a wise criticism. People, readers of papers or others, will always carry their wares to the best market, and the only effective way of dealing with the situation is for the members and officers of this Institution to strive to make our market the best. Those who read papers on electrical subjects in other institutions are in reality doing a great good to the electrical industry and to this Institution, as they play the part of the missionary who goes out into the wilds, spreads the light and eventually gathers converts into the fold. I therefore say that our members who read papers before other institutions or societies are well-doers, and should not be submitted to the unfair criticism which emanates from a spirit akin to some of the elements of trade unionism, and which is much to be deprecated. While admitting the desirability of the existence of these electrical missionaries, I also urge that the members and officers of the Institution should leave no stone unturned in their search for what is good and useful to the Institution. Our predecessors have done this, and the task of the present Council and members should be much easier than the task which their forerunners have performed. What they accomplished is made clear by a reference to our membership. An Institution, which in 1871 numbered 80 persons, and to-day numbers 4,800, has every reason to be proud of its development and growth. It is my belief that the Institution will continue to develop, and if it is governed in a tolerant and broad-minded spirit will never cease to be the referee in all cases affecting electrical science and industry.

I now propose to lay before you some matter I have had collected relating to the effect that existing legislation has had on electrical enterprise, and containing a few suggestions for the betterment of the present situation.

As the generation and supply of electricity for lighting, power, or traction are strictly regulated by Act of Parliament, it is obvious that electrical progress must be seriously affected for good or for evil by

the state of the law relating to electricity. It is impossible to attempt here to cover the whole field of electrical legislation, but attention may be directed to one or two special points.

If we omit the Electric Lighting (Clauses) Act of 1899, which merely codifies the provisions usually incorporated in a Provisional Order granted by the Board of Trade, we find that there has been no public legislation upon the generation and distribution of electricity since 1888, when an Act was passed to amend certain defects in the original Act of 1882. This absence of legislation during a period in which the applications of electricity to the service of mankind have been enormously improved and extended, would not be remarkable if the original Acts had been adequate not only to the needs of the time at which they were passed, but to those of the present day; but, as every one knows, this is far from being the case. Those Statutes were framed to meet the case of distribution of electricity over a small area, and no provision was made for the time, which has long since arrived, when it would be possible and even economical to distribute from a given centre over a wide area, extending far beyond the boundaries of any particular parish or municipality. There might still have been a chance that the parochial idea embodied in these early Statutes would in the course of time have been abandoned, had not Parliament fixed this idea as a permanent feature of British electrical distribution by giving to the local authorities the right of purchase of the undertakings supplying their areas after a period which was first stated at twenty-one years, but was afterwards extended by the Act of 1888 to forty-two years. In addition to this, the Act of 1888, although intended to promote the introduction of electric lighting, went far towards stifling private enterprise in this direction, by giving to the local authorities a veto on any petition to supply electricity within their areas. Thus it has come to pass that in spite of the great progress made since 1888 in the science of distribution, no one but a local authority can to-day obtain free unimpeded access to the Board of Trade with a petition for a Provisional Order, and as local authorities are as jealous of one another as they are of private companies, the general result is that the municipal area is still the unit area for distribution.

There are, of course, many other prominent defects in the Electric Lighting Acts. They do not, for example, provide for the compulsory purchase and sale of sites for generating stations, nor yet for the erection of these stations outside the area of supply. If promoters of an undertaking desire either of these things they must proceed by Special Act, not by Provisional Order; and the best proof of the inadequacy of the Electric Lighting Acts to modern needs is that these private Acts usually contain special clauses of which the object is to render inapplicable a larger or smaller number of the sections of the controlling public Statutes. The whole subject was considered in 1898 by Lord Cross's Committee, which made many recommendations of the highest value—among them, the abolition of the veto and the removal of the defects just noticed; but until the present year the Government has shown no sign of being desirous or willing to give these recommendations the force of law. The Institution of Electrical Engineers, which

has always been alive to the serious consequences of this defective legislation, sought in June of last year to bring pressure upon the Government, by sending a deputation to the President of the Board of Trade. It is impossible to express more forcibly or more clearly the objections to the present law than was done by the members of our deputation on that occasion; but although we were then promised a measure to remove these objections, nothing was attempted until May of this year, when a Bill, embodying most of the recommendations of Lord Cross's Committee, was introduced in the House of Lords by Lord Wolverton at the instance of the Board of Trade. But the Bill did not get beyond the introductory stage, and at the close of the session no progress had been made. The measure, however, must not be allowed to drop; and as the President of the Board of Trade has told us that his department desired to "press forward" this measure when opportunity offered, we may express the hope that next session it may not only be introduced, but may be placed upon the Statute-book.

With regard to the distribution of electricity for Power purposes, the Electric Lighting Acts make no special provision. Any consumer may use his supply either for Lighting or Power, or both. But in recent years the idea of promoting large Power schemes to supply very wide areas has come prominently to the front, and since 1900 several such schemes have been authorised by special Acts of Parliament. The powers of supply conferred upon companies under these Acts are twofold: they may supply energy for Power purposes to any person, and they may supply energy in bulk to authorised distributors. In this connection it may be noted that if the Bill introduced by Lord Wolverton becomes law, it will be possible to obtain powers for supply in bulk to authorised distributors by Provisional Order, instead of proceeding, as at present, by Special Act. The most important point, however, about these modern Power schemes is that in many cases the promoters come into sharp conflict with local authorities and other authorised distributors supplying urban or rural districts within the large area which they desire to cover by their scheme. The local authorities are especially antagonistic to any proposal which would allow another body to come into their area to supply electricity, and in some cases Parliament has cut out, from the area which a particular scheme desired to cover, various towns and districts possessing their own electricity supply undertakings. Now it seems desirable that the local authorities should consider carefully the advantages of taking their supply in bulk from a power scheme, instead of generating for themselves on a small scale. In very many cases it would be much more economical to do so, and they would still be left the sole distributors in their own areas. But if local authorities will not do this, Parliament must consider what is best for the country at large; and as the rural districts must obviously gain by the supply of electrical energy at cheap rates, the towns should not be allowed to prevent this gain by obstructing or rendering ineffective the scheme for the larger area. The point is that if all the towns, which constitute the "fat" districts, are cut out of these schemes, leaving only the "lean" rural districts for the large-area companies, there can be little or no

hope of financial success. In order to obtain, therefore, the greatest good for the greatest number, the larger authority ought to be allowed wherever possible to prevail over the smaller municipalities opposing it, especially when we consider that this does not entail an injustice to these municipalities, but only a slight narrowing of the field of municipal enterprise.

It remains to consider what is, perhaps, the most remarkable feature in recent electrical progress—the development of the electric tramway. The law relating to this branch of the subject is, unfortunately, still more unsatisfactory than that dealing with lighting and power, for the controlling Act is still the Tramways Act of 1870, which was passed before electric traction was introduced, and was intended to deal simply with the ordinary horse-tramway. The defects of that Act are too well known to require mention here; the objectionable veto given to the local authorities has once more been sufficient in itself to retard progress to an extraordinary degree. The fact that in the last few years electric tramways have developed so much in this country is not due to the existence of the Tramways Act, but principally to the fact that it was found possible to evade that Act to a considerable extent by promoting these concerns under the Light Railways Act, 1896—an Act which was really intended for another class of undertaking altogether. That Act has proved beneficial to a high degree, as it lowers the cost and simplifies the procedure when a tramway scheme is promoted; but in the years during which it has been in operation, various defects have been discovered and attempts have from time to time been made to have them remedied. My predecessor, Mr. Swinburne, pointed out these defects to the President of the Board of Trade when our deputation waited upon that Minister last year, and here, again, we were promised a measure to remedy them. A Bill *was* introduced this year, but it was unsatisfactory in the extreme, as it made no attempt to deal with the whole subject, but merely tinkered at one or two details; and we cannot regret, therefore, that it made no progress. The Board of Trade had previously appointed a Committee to consider what amendments of the Act of 1896 were desirable, and as the President of the Board of Trade told our deputation that a report had been received from that Committee, we naturally expected that the new Bill would deal comprehensively with the subject, but in this we have been disappointed. The old Tramways Act of 1870 ought to be repealed, and replaced by a measure suitable for modern needs. Under the Light Railways Act of 1896, which is in part applicable to electric tramways, the powers of the Commissioners might with great advantage be extended. At present they are hampered by the feeling that, if not bound by the letter of the Tramways Act of 1870, they must, as far as possible, respect its spirit; and hence the absence of consents from local authorities has more weight than is proper. In cases where a light railway scheme is likely to compete with an existing railway company, the provision that the promotors must proceed by private Bill, and not by an inquiry before the Light Railway Commissioners, also militates considerably against the usefulness of the Light Railways Act by curtailing the powers of the Commissioners; and this restriction ought to receive attention in any amending measure.

These are but a few of the numerous points in the present law which call for attention. The whole of our electrical legislation is in urgent need of reform; and, after so many promises have been made, it will be very regrettable if nothing is done to remove the existing defects.

While the Electric Light and Power undertakings have obtained but little legislation in their favour, it is a relief to see that Parliament has granted Railway Companies certain advantages. By the Railways (Electrical Power) Act, which received the Royal Assent on the 14th of August last, existing railway companies, desiring to convert any of their lines to electric traction, are enabled to obtain sufficient powers for so doing by means of an Order of the Board of Trade. They may become interested in Power Companies and may take from them electrical energy for the supply of their main or branch lines.

In spite of the legal impediments referred to, it will be found on investigation that substantial progress has been made in Great Britain in the utilisation of the electric current for both light and power purposes.

Exclusive of traction motors, in March of this year, lamps and motors equivalent to over 14,000,000 8-c.p. lamps were connected to the mains of public electricity supply undertakings, the Metropolis being represented to the extent of about 5,000,000. There were about 300 towns enjoying the advantage of an electricity supply, this number including, with two exceptions, all the towns whose population exceeds 100,000. The exceptions were Tottenham and the Rhondda district, which did not seem anxious to be alongside of their 38 fellows. It appears that at this period, exclusive of power companies, the public supply stations had motors amounting to 55,000 H.P. connected to their mains.

Municipal undertakings own generating plant of a rated capacity of 320,000 kilowatts, and private undertakings are represented by 160,000. In the Metropolis the companies are proprietors of about 100,000 kilowatts, whereas the public bodies are responsible for approximately 28,000. The pre-eminence of the companies in London is due to the fact that they acted as the pioneers and were first in the field. The average rated capacity of a British station appears to be about 1,400 kilowatts. It is to be remarked that while in the provinces the average municipal station has a capacity of nearly three times that of a company station, in the Metropolis the ratio is reversed. Again, the average Metropolitan company has, approximately, ten times the plant capacity of the average Provincial company.

It is interesting in this investigation to note that modern tendencies in this country are decidedly in favour of the direct-current system with a three-wire distribution; the number of direct-current undertakings increased from 139 in 1901 to 214 in 1902 and 260 in 1903. For these three years the alternating-current stations numbered 67, 68 and 69 respectively. There are now established in Great Britain 13 two-phase and 5 three-phase stations, exclusive of power-transmission stations. In 29 cases supply is given on two or even more systems. Many of the alternating-current stations have taken up the supply of direct current, others have added two-phase or three-phase

supply to their single-phase service, or have changed over completely to one of these. The direct-current system appears to be in no immediate danger of supersession, in part owing to the raising of the voltage, and the consequent possible extension of the service area. The number of voltages in use is somewhat confusing, and presents to the Standards Committee a difficult problem to solve. These voltages now amount to about 16, and out of 289 examples of pressures nearly one-third are declared at 230, more than one-sixth are given as 220, while voltages of 240, 200 and 100 claim about one-eighth each. There are between fifty and sixty stations which revel in more than one declared pressure. The extent to which the change from one voltage to another has taken place may be judged from the fact that in 234 cases the pressure is upwards of 200 volts; 64 supply current both above and below 200, and there are only 29 whose supply is entirely under 200 volts.

Although at the present moment the efficiency of carbon glow lamps and, in certain cases, of arc lamps is not so great at the higher voltages, yet it cannot be gainsaid that the change of voltage has been a beneficial one both for the supplier and the consumer. The supplier has benefited through a more profitable use of his current conductors; this benefit has considerably more than outweighed the expenditure, in other directions, that the change entailed. In many cases one of the large expenditures must have been in the purchase of storage batteries, for it appears that out of 330 stations no fewer than 240 use these batteries to a greater or less extent. The only drawback to the change would appear to exist in the case of small motors.

Some remarks on the methods of charging for current could be made, but I limit myself to pointing out that the number of lighting undertakings in which the maximum-demand system is employed alone is now 104 as compared with 114 in 1902, or say 31½ per cent. instead of 40 per cent. of the totals of the respective years. The maximum-demand system in conjunction with one or more other systems is used in 74 cases, as against 38 in 1902, or say 22½ per cent. as compared with 13½ per cent. A simple uniform-rate gives the corresponding figures of 70 and 63, representing 21½ per cent. against 22 per cent. I regret I have not been able to collect information with regard to private installations in Great Britian, which would prove sufficiently comprehensive. I have therefore decided to leave this portion of the subject alone.

There is still room for improvement in the carbon glow lamps. I am given to undertand that 16-c.p. lamps for 200 volts and upwards, with a life of 1,000 hours at an average consumption per candle of even 4 watts, can hardly be obtained as a commercial article. The production of the Nernst lamp seems to be improving, and its employment in a large number of towns for street lighting, and in many private installations, will enable people to thoroughly appreciate its merits and utility. I find that the most recently introduced pattern gives three-quarters of a candle per watt when new. Nernst lamps are used by about 1,000 supply companies in the United States, the Hartford (Connecticut) Company alone employing about 4,000. In many cases these lamps

are maintained by the supply company without extra charge, or at a nominal cost. The Osmium lamp of Auer von Welsbach is well spoken of for low voltages in some quarters. Twenty-five to 30 volt lamps have been made which show little diminution in light-giving power after 800 to 1,000 hours burning. Apparently they absorb about 1·5 watts per candle, but are expensive to purchase. We shall doubtless hear more of the mercury vapour lamp associated with the name of Mr. Cooper Hewitt.

While, with alternating-current work, the tendency is always to simplify the switch-gear to the utmost, this does not seem to be universally the case in direct-current practice, at any rate in the smaller public supply stations. Some of these have elaborate plug-boards, numerous 'bus-bars, expensive battery regulators, and all sorts of alternative ways of doing the same thing. In many cases where these complications do not exist, not only the comfort of the staff but the efficiency of the service are greatly increased. It appears to be forgotten that everything tending to simplicity has a beauty of its own which no complication can ever rival. In spite of the absence of any notable development in switch-gear, a very high standard has been attained by British designers, especially in heavy power and lighting work with alternating currents at high pressure. Following a totally different line from the Continental and American practice, our engineers have evolved apparatus which is at the same time safe, simple, and reliable, while occupying a minimum of space.

In the early days of the electrical industry when the range of possible distribution of current was restricted, the engineer had to seek a site for his generating station in crowded and expensive districts. To economise space he employed high-speed reciprocating engines and water-tube boilers. At that period he could doubtless do this with advantage, as the generator units in use were, comparatively speaking, small. To-day the units are larger and the range of possible distribution is increased. It is not, therefore, so necessary to follow the old practice, and in many cases to do so is inadvisable.

Among the remarkable things of the year may be mentioned as in course of construction, four Turbo-generators of the Parsons type, each rated at 5,500 to 8,280 kilowatts, and occupying a space measuring only $51\frac{3}{4} \times 14 \times 12$ feet. A 6,500 kilowatt turbo-generating set is being built by Brown Boveri & Co. which measures $59 \times 10 \times 10$ feet. A Curtis turbine of 5,000 kilowatts is running in Chicago; this turbine is a combination of the Parsons and De Laval systems and is arranged with a vertical shaft, a somewhat inadvisable design. In shape it is cylindrical, and, including turbine and generator, stands 25 ft. high with a diameter of 14 ft. It may be interesting to note that there are over half a million H.P. of turbines in use or on order, and 24 stations in this country use the turbine more or less. While referring to large units, it may be of value to state that the Société Cockerill of Seraing is expected to show at the St. Louis Exhibition next year a gas engine of 3,000 H.P.; this engine will have two cylinders, each of 51 inches diameter, and will run at 85 revolutions per minute. It is said that the Gasmotoren Fabrik Deutz is designing a 6,000 H.P. engine.

With relation to the employment of electricity in factories and ships, we all remember the excellent papers read before this Institution by Mr. A. D. Williamson and by the late Mr. C. E. Groves. The contribution of the latter was especially interesting to me, as it showed in a striking manner the progress in the employment of the electric current on shipboard from the time of the Silvertown Company's installation on their cable steamer *Dacia* in 1879, down to the huge developments already reached at the time the paper was read.

Among the recent varied uses to which electro-motors can be put may be mentioned gold-mining at the Klondike, where they are employed in dredging, washing, and conveying the material to the tip. Another instance is the driving of a rolling-mill, where a 400 H.P. motor is coupled direct to the rolls. In a large plate-glass works in America there are four generating sets of 4,000 kilowatts each and one set of 350 kilowatts; there are also 20 motors of 450 H.P. each and 20 of 200 H.P.; the three-phase system is in use at 5,800 volts with frequencies of 40 and 25 cycles per second. A large colliery in the same country has plant of 2,900 kilowatts, the installation comprising 44 mining locomotives and 75 miles of underground trolley wire; the power is transmitted at 5,600 volts, three-phase 25 cycles per second, but is converted for use at 275 volts. At the Carnegie Works electricity is used for almost everything requiring power, and it is stated that in the Homestead Steel Works of Pennsylvania, by the aid of electricity 4,000 men make as much steel as is made at Krupp's with 15,000 men.

Since the establishing of the Portrush electric tramway in 1883 the electrical engineer has encroached on the field of the tramway engineer, and consequently the purely tramway work as apart from the electrical work has often shown the mark of the active, clever but untrained mind, impossible curves and grades being attempted, and unnecesarily expensive work being done. There has been some advantage in this no doubt, as the experience gained by these works, although expensive, has tended to improvements in practice. There is an American manner in this mode of procedure which leads to a free use of the scrap heap. The individual suffers, but the community eventually gains by the survival of the fittest. It is, I suppose, a rule which applies and must apply to all young nations and industries. The rough and tumble while it lasts is interesting and exciting, and doubtless drives the workers to put their best foot foremost. The golden rule, "Be sure you are right and go ahead," is the best to follow, but it often happens that one dies and is taken from the arena before even the first part of the rule is complied with. On the whole, therefore, it is perhaps as well that chance should be allowed to play its part, and that activity and energy should not be troubled with a too severe bearing-rein. The rule before cited should probably be modified in the manner of the saying of the northern farmer to his son, and should read, "Be sure you are right and go ahead, but go ahead." I think this has been the motto that has been adopted by electrical engineers since 1877, with the much desired effect that sufficient improvement has been made to enable the electrical bark of this country to be steered into still water for a time. This happy condition does not, I believe, exist in Germany

or America, where apparently there are "more heads to be broke." We have been toiling up a steep hill for many years, and the time has now arrived when we should stop and survey the landscape as a whole, instead of narrowing our view to the particular point towards which we happen at the moment to be ascending. Already many of the paymasters are questioning the scrap-heap theory, as they know by experience that this is often evolved from nothing but a craving for change, and a want of appreciation of the true value of money on the part of their advisers. I make these remarks with no desire to convey the idea that work in this country is not carried out conscientiously and well, but rather with the view of suggesting a curbing of the expenditure of money which produces a semblance for the moment of unbounded prosperity, while in reality it only means riding full gallop for a fall. If the fall should occur, the many men who are entering our ranks every day and swelling our numbers will find their prospects blighted owing to a disturbance of the trust which is placed in the electrical engineers of to-day by those who supply the sinews of war. I, therefore, think it incumbent on every electrical engineer carefully to weigh every recommendation he may make, not from the point of view of immediate, but rather from that of ultimate efficiency, and to deal with every possible factor in drawing his estimates. The papers read, and the discussions which take place in this hall, and in the meeting places of our Local Sections, tend to this end.

I am afraid I am wearying you by reiteration, but I feel strongly on this subject, which, in my opinion, affects the vital interests of the Institution, and I venture to lay before you things that though perhaps to many of you are platitudes, may prove of use to our younger colleagues. The establishing of electrical tramways, and the electrification of existing railway and tramway lines, are rapidly assuming great proportions, and it is not difficult to predict that this branch of electrical engineering will continue to advance by leaps and bounds, providing employment for many electrical engineers connected with the Institution. From the report of the London County Council on the excellent work they have been doing in South London, it would appear that the difference in prime cost between laying an urban line on the conduit system and construction on an overhead trolley system is not so great as to render the former altogether impracticable. I think, therefore, those authorities in the municipal areas are acting in the best interests of the inhabitants of this crowded metropolis, who refuse to authorise erection of the unsightly, and in many cases dangerous, overhead conductors. The utilitarian may argue that whatever increases prime cost goes in restriction of development, and in this he is to a certain extent correct. But apart from the question of danger avoided, it is usual in civilised communities to have some respect for forms and appearances as well as for the purely useful. Moderation should reign in all things, and in relation to electrical tramways London does better to employ the conduit system and follow the example of Budapest and Paris, rather than erect an overhead system similar to that which disfigures my native city of Glasgow, and many other towns in this country. The conduit system has cost London per mile of single line

about £14,000, an overhead installation would have cost £7,000. In my opinion the difference is well spent. It may be argued that this difference does not represent the whole difference, and that many electrical arrangements can be made in an overhead system that would not be permitted in a conduit system. My answer to this is that it comes within the province of us engineers to overcome these difficulties, overcome them we shall if we only apply ourselves seriously to the task, and produce results which will pass the severest test that the Home Office, Board of Trade, or other authority may impose.

Passing on to the nature of the current supply, the continuous-current system predominates at present in Great Britain for all kinds of electric traction. Its supremacy is again being threatened by the monophase system, whose employment in certain cases possesses advantages that are greater than the disadvantages. The efficiency for traction purposes of polyphase working has not been sufficiently proved, but as regards the method of transmitting power to considerable distances for conversion to continuous current to be applied to tramway purposes, the three-phase system has so far held the field at pressures up to 6,500 volts. A most complete system of high-pressure polyphase traction work was inspected by many members of the Institution during a visit to Northern Italy in the spring of this year, and to those interested in this subject it will be useful to closely follow the fortunes of the electrified Valtellina, Lecco and Milan Railway. For this line there are in course of construction electric locomotives, which have been designed to exert a tractive force of from 7,500 to 11,000 lbs., at a speed of 40 miles per hour, their individual output being, I understand, from 800 to 1,200 H.P. The exceedingly interesting experiments being made on the Marienfelde-Zossen Military Railway have resulted so far in the attainment of a speed rated at 125 miles per hour. The railway from Berlin to Zossen is about 15 miles in length, and the current generating station is about 8 miles from the head of the line. The car, a Siemens & Halske design, was supplied with power from the line wire at a pressure of about 14,000 volts.* The inauguration of through traffic between Liverpool and Bolton, a distance of 40 miles, marks an important epoch in the progress of the South Lancashire Tramway project, which embraces a network of more than 500 miles of track, and will serve an area whose population is about 5,000,000.

The application of electric traction to our railways is progressing. At present the sections which are being dealt with are those which have a great traffic density or a frequent service. This policy is doubtless a wise one, as the railway companies limit the application of a considerable capital expenditure to the best paying division of their lines, and to those portions where the benefits to be derived are the most apparent. During the current year, the first section of the Metropolitan-District Railway conversion has been made, and it is expected before March of next year that the Moorgate Street-Drayton

* Since writing the foregoing I notice that the car designed by the Allgemeine Electricitäts Gesellschaft has, on the same line, attained a speed of 130½ miles per hour.

Park and Drayton Park-Finsbury Park sections of the Great Northern and City Railway Company will be in operation. The Mersey Tunnel Railway has been completed, and the conversion of the Wirral Railway is under consideration. The North Eastern Railway has had trial runs along Tyneside, and good progress is being made with the Liverpool-Southport line. The Central London Railway is completing the change from locomotive to motor-car driving. The motor-car system is generally accepted as the best form for passenger traffic for many reasons which I need not recapitulate. The direct-current system at 500 to 700 volts appears to remain as a standard for railway work of this class, as well as for tramway work, but there are signs that single-phase alternating current may prove a rival. In the United States the Washington Annapolis Railway is being equipped with an overhead system, which will deliver direct to the motors a single-phase current at 3,000 volts. The three-wire system of feeding tramways and railways, though not without examples abroad, has not been adopted in this country save on the City and South London Railway, where it seems to have proved satisfactory.

The only surface contact system in this country is that which has had nearly a year's trial at Wolverhampton. Troubles have arisen between the Corporation and the Company; it is, therefore, impossible to say exactly how the matter stands. It is believed that the Kingsland Mechanical Switch Surface Contact system may be tried at Dresden shortly.

Although accumulators are being extensively used for private carriages in London and elsewhere, yet this country has not seen its way to employ them for rail or tramways. In Italy and Germany some use is made of them, and it is stated that as the result of two years' working on lines running out of Bologna, the cost of battery traction has proven 28 per cent. cheaper than steam. The use of storage battery locomotives in America for shunting and mine work appears worthy of mention, as it seems to have attained considerable proportions, and to have proved successful in practice.

In the provinces the great power distribution undertakings are getting to work by degrees. Besides the Midland and Newcastle concerns we can now count the Durham, Lancashire, North Metropolitan and South Wales Companies. The advantages of electricity as a motive power seem to be readily appreciated by the industrial populations of these districts. Among some of the large schemes in project is the electrification of the National Railways of Sweden, the original power being derived from water pressure or from the combustion of peat. Estimates are being drawn for 2,700 miles of railway, calling for over 100,000 H.P. The official estimate shows that there will result a saving of 50 per cent. in the present working expenses, which amount to about £800,000 per annum. [In making this statement I must point out that the figures are in no way mine.] Switzerland again speaks of a conversion of its National lines, entailing the use of 30,000 H.P. to be obtained from water pressure.

The utilisation of the Victoria Falls of the Zambesi is a project under serious consideration, and at least a portion of the scheme may

be near realisation. Some three months ago certain details of the scheme were made public, and from these it appears that whereas the Niagara Falls are equivalent to a continuous loss of 7,000,000 H.P., at the Victoria Falls of the Zambesi the loss is five times as great. In advocating the utilisation of this waste it is pointed out that tramways near San Francisco are driven by a current which has its origin in the Ubax Falls about 220 miles away, and that some American engineers estimated that power, given a steady load of 24 hours per day, could be delivered 330 miles from the generating plant at about £4 10s. per kilowatt per annum. At Niagara, six Syndicates are carrying out work which when completed, will be capable of generating over one million horse-power. Some of the generating sets will be of 10,000 H.P. working at 11,000 volts. The pressure will be converted to 60,000 volts. The highest pressure as yet made use of in Europe for power transmission is in Italy, namely, 40,000 volts. The plant is not yet completed; it is intended that water power will develop 7,500 kilowatts at 9,000 volts (42 cycles per second), which will be transformed to 40,000 volts for transmission. In the United States, in Montana, where a similar pressure is employed for transmission, the voltage was increased to 80,000 for a few hours with success. Consideration of these voltages recalls the experiments made in March, 1883, just twenty years ago, by Marcel Desprez, in power transmission between Paris and Creil, a distance of 57 kilometres at a pressure of 5,700 volts. One also thinks of the transformer of Gaulard of about that period.

I now turn to the subject which gave birth to this Institution and from which its first title was derived, I mean the subject of Telegraphy. Between the 26th of May and the 7th of July of this year an International Conference of the Telegraph Administrations was held in London at the invitation of His Majesty's Government. These meetings are, so far as may be, quinquennial, and are usually held in the capitals of the Great Powers. The last meeting in London took place in 1879. The discussions which now are carried on between the Government Delegates, and with the representatives of the Telegraph Companies who are also invited to be present, are purely of an administrative order, and principally deal with tariffs and the rules for carrying out the international exchange of telegrams. Technical questions such as the size of conductors and the classes of instruments to be employed in the international service are either already agreed upon or are the subject of separate and private understandings between the Administrations interested. These have been fairly well standardised during the 38 years that have elapsed since the first Conference was held in Paris.

Since 1879 the growth in the length of telegraph land lines has been very large, and the development of submarine telegraphy has been almost phenomenal. At that date the public were just beginning to realise what power for good or for evil was being placed at their disposal. Merchants were beginning to feel that the submarine telegraph had a centralising effect which enabled them to carry on their business with smaller stocks of goods. The large merchant had no longer the control of the foreign markets which his wealth had

formerly given him, and the small merchants began to have an innings. When this state of things came home to the traders, submarine telegraphic facilities were in great demand; the cables across the Atlantic and other oceans began to multiply, and new centres of industry were connected to the chain. The men at the head of cable affairs, and notably the late Sir John Pender, were not slow to meet these developments by increasing the ramifications of the telegraphic network, and bringing the charges for telegrams to such a figure as to encourage the public to make full use of the means of inter-communication placed at their disposal. This policy was hastened by the wholesome dread of competition, where such did not exist, and by competition itself. A year ago, the gap in the world's telegraphic girdle was completed by the laying of the trans-Pacific cable which now unites Canada with Australia, and this year has seen completed a second line across the Pacific from San Francisco to the Philippines and China by way of the Sandwich Islands, Midway and Guam.

It is strange that during this development, the improvements in the types of telegraph cable employed have not been great, nor has there been any great advance made in the design of the instruments used for the transmission of signals, but the administrative work has been vastly bettered. Messages which formerly took hours in transmission are now received from the public and delivered to the addressees in a few minutes. I am informed that a telegram announcing the result of the yacht race for the America Cup was carried, in August last, from London to South Australia in four minutes. This message, which was forwarded *via* South Africa, was handled by 15 operators, passed through 11 stations, and traversed 14,404 nautical miles of submarine cable and 1,515 statute miles of land lines. Ordinary commercial traffic can not be dealt with at this speed, but the instance I quote shows what can be accomplished when special arrangements are made to carry news which is of peculiar interest. The manager of an American Cable Company has told me that the result of the America Cup Race reached London one minute after the termination of the race, having been transmitted through 3,400 nautical miles of submarine cable, and some 200 statute miles of land wire. The record time between New York and London is thirty seconds, and messages have been sent and replies received in one minute and thirty seconds.

During the last twenty-five years, the engineers engaged in submarine telegraph work have devoted more care to the surveys of route than was previously the practice; to a great extent this means that the engineers have succeeded in persuading the capitalists that these surveys are of prime importance. The Atlantic cables of 1857-8, of 1865, 1866, and on to 1874 were laid on the data as to the ocean bed furnished by perhaps thirty soundings taken over a route some 1,700 nautical miles long. In 1871, Lord Kelvin furnished a means for sounding which did not exist previously, and in 1872 the Silvertown Company made a first trial of this method. The late Sir William Siemens, in 1874, carried out the first systematic sounding in the Atlantic, and from that time forward until 1883 it was the habit to take soundings, but not to make a full and careful survey. With the

results obtained from these soundings our knowledge of the ocean bed was increased to the extent of teaching us that submarine mountains, plains, and gullies exist, and that the physical conditions of the submarine floor are very similar to what one observes in travelling through Europe from Calais to Brindisi. In 1883, the first thorough preliminary survey of any cable route was made, but as this has been the subject of a paper read before the Institution on the 10th of November, 1887, I need not enter into detail, further than to say that the result of this survey materially altered the original plans for laying the cable on account of unsuspected elevations and depressions of the ocean floor having been discovered. In addition to the configuration difficulties to be encountered by a submarine cable, the chemical composition of the soil is important, as it greatly affects the cable's life. A paper referring to this subject was read before the Institution on the 11th of March, 1897. I had the pleasure of handling, about a month ago, a piece of submarine cable which had lain at the bottom of the sea in deep water for nearly thirty years, and its appearance was such that I was unable to say whether it could not have lain there for another thirty years without showing any deterioration. To-day there are employed in cable work 47 ships representing 92,094 tons. The largest, the *Colonia*, belongs to the Telegraph Construction and Maintenance Company, and has a dead-weight capacity of 11,000 tons. When he considers the comparative facility with which cables are now repaired, no shareholder in a submarine telegraph company needs fear for the permanency of his property. In July, 1879 there were 50,450 nautical miles of cable in operation; there are now under the sea 222,253 nautical miles, and I have every reason to believe that this mileage will continue to increase.

On wireless telegraphy I have no new developments to report. The Cantor Lectures delivered by our Vice-President, Professor J. A. Fleming, before the Society of Arts in March of this year, and the description of the Lodge-Muirhead system in *Page's Magazine* for last May, give to any one interested in the subject the latest communicated information of any value. I need only add that there seems no immediate prospect of its seriously competing with the business of the existing telegraph companies.

In my remarks concerning the means of transmission through submarine cables, I omitted to make reference to the relay of Mr. S. G. Brown which was described by him in the paper he read before the Institution on the 1st of May of last year. I may also mention that since 1879 considerable improvements, though of a minor nature, have been made in duplex transmission.

The use of the telephone continues to extend, and in addition to the greater facilities offered in Great Britain there are gradually being established international wires which place in telephonic communication the principal towns of Great Britain and several of the commercial centres on the Continent.

So far as I am aware no practical use has yet been made of Poulsens teleautograph, which I had the pleasure of inspecting with our Vice-President, Mr. Gavey, and of which he gave a description in a communication to the Institution on the 22nd of November, 1900.

Before passing to the next portion of my subject, I should like to make a short reference to a very early investigator into the phenomena of magnetism: I mean Dr. William Gilbert.

Our Past-President, Dr. Silvanus Thompson, who has taken so great an interest in the bibliography connected with Gilbert, tells me that the tercentenary of the death of this remarkable man will occur on the 10th of December next (new style), and that probably some notice of the fact will be taken by his native town, Colchester, and by the Royal College of Physicians, of which body Gilbert was President at the time of his death. As you are doubtless aware, the work by Gilbert, notably his "De Magnete Magneticisque et Magno-magnete Tellure," shows a patient observation and careful recording of results, which resemble in many ways the method of Michael Faraday.

Your Council have not yet decided what steps, if any, will be taken by the Institution in connection with this celebration.

Whilst reviewing the state of electrical progress, mention should be made of the work of the Engineering Standards Committee.

This Committee is making some progress in its work, and it is pleasing to note that the Government has recognised that the Institution of Civil Engineers, the Institution of Mechanical Engineers, the Institution of Naval Architects, the Iron and Steel Institute, and this Institution should be assisted in the useful work they are doing. A Government grant has been made which will lighten the burden of these Institutions, as until this assistance was received they were not only doing the work, but were also providing the funds necessary for carrying it out. Sir William Preece and Colonel Crompton, two of our Past-Presidents, are members of the General Committee and represent the Institution. The former is Chairman of the Electrical Plant Divisional Committee, which is most directly connected with our branch of the subject. It is to be hoped that some of the results of the deliberations of the Electrical Plant Committee may shortly be published, and should they be, I shall append them to this address by way of further publication.

While speaking of the work of the Engineering Standards Committee, I cannot resist the temptation to protest against the continual attempts which are made to apply to our weights and measures and money, what is called the decimal system. However regrettable it is that scientific men should not have boldly adopted for their purposes twelve instead of ten as the place ratio of figures when so many sweeping changes were made at the time of the French Revolution, I am afraid they are too indolent to do so now, and that ten will continue in use until another universal upheaval changes all things. Because ten is conventionally adopted for this ratio, there appears to me no reason why the system should be extended to all the weights and measures necessary for common use, bringing about many absurdities, and in many cases establishing very inconvenient standards. The adoption of the metre or any other measure of about its dimensions as a unit of length matters little, but if the metre be adopted, it is no reason because a millilitre of distilled water is supposed to weigh one gramme at 4° Celsius in vacuo that butter, coals, diamonds, and wood

should be compulsorily dealt with in metres or their decimal derivatives. I am the first to admit that in physics and chemistry there are undoubted advantages in having, so far as one can, a common relation existing between the various units, and, as the decimal relation is convenient, the chemists and physicists are doubtless right in adopting the Decimal and Metric system for their weights and measures. But that is no reason why we should combine to force on the public for ordinary use a system of weights, measures, and money which is so much against nature that it with difficulty obtains currency in the countries of its adoption. In France, precious stones are to-day bought and sold in carats; firewood in cordes; milk in pintes; gravel in toises; grain, potatoes and charcoal in boisseaux; wine in barriques, feuillettes, demi-setiers and chopines; wood for construction in pieds, pouces and lignes; beer in canettes and pots; sugar and coffee among the poor people are dealt with in livres, demi-livres, etc. Cattle dealing is carried on in pistoles and écus, and not in francs. Finally, the French Government has just issued a twenty-five centime piece, doubtless because it represents a quarter of a franc. In my opinion, the decimal system applied to weights and measures and money *offers too limited a field* for the operations of ordinary life; and I should be sorry to see it with all its disadvantages forced upon us by legislation to the exclusion of other systems, when the admitted advantages to be gained are so small.*

I should now like to make a few remarks, if time will admit, on the present functions of Electro-chemistry.

This is one of the most progressive branches of electrical industry; although striking advances are rare, constant improvements in detail are being made, and processes which have been long outlined are being developed into commercially practicable methods.

Probably there has been no step so noteworthy during the year as the announcement by Mr. James Swinburne of his invention of a new process for the reduction of metallic sulphide ores, which, with the collaboration of Mr. Ashcroft, he has put to test on a commercial scale. The process consists in treating the ores with chlorine, to displac the sulphur—which is recovered; the essence of the invention being the fact that this reaction takes place without the formation of chloride of sulphur; various precipitations follow, according to the metals present, the final result, after all the other materials have been extracted, being zinc chloride. This is electrolysed, the zinc being obtained in the metallic state, and the chlorine remaining ready to be utilised again. Thus the process is cyclic, and it is applicable to almost all kinds of ores, including the huge piles of waste which have accumulated as the result of less complete processes. This system may well prove of the utmost importance in metallurgy.

Another valuable process, which has made considerable progress during the past year, is the reduction of iron ores by means of the electric furnace. At Livet, in France, the process is in practical

* I notice Mr. Seddon has had an enabling Act passed through the New Zealand Parliament by which the Governor can, after January 1, 1906, by Proclamation make the Decimal and Metric system compulsory in that colony.

operation, generators of 1,200 H.P. each giving single-phase current at 30,000 amperes each, and driven by water power, being employed. The output is 12 tons of steel per day. At these works ferro-silicon is also made from quartz, scrap iron and coke, at less cost than that of smelting; and copper pyrites is reduced to copper and iron sulphides, rich in copper, and made ready for the ordinary smelting process. Steel of high quality is similarly produced in Sweden at the rate of 1,500 tons per annum. With the Stassano process the expenditure of energy is said to be 3,000 H.P.-hrs. per ton of iron; but with the Ruthenburg system, it is said that 500 k.w.-hrs. suffice, and that ores of poor quality can be treated. Large deposits of iron ore exist in Canada, remote from coal mines, but within reach of Niagara Falls, and it is said that a Canadian syndicate has been formed to work the Ruthenburg system with power derived from the Canadian Niagara Falls hydro-electric works.

Already in Canada the Betts process for refining lead is in operation —at Trail, B. Columbia—the daily production amounting to 7 tons of lead. The crude lead is used as anode in a bath of lead fluosilicate and fluosilicic acid; there are 22 anodes per vat, through which 4,000 amperes are passed, and the pure metal is deposited on the kathode, leaving the impurities, including the precious metals and copper, on the anode in a skeleton of spongy lead.

In a quite different direction electricity is being used for the purification of the water supply of towns. There are two installations of this kind in Germany—Schierstein and Paderborn—where the Siemens ozonising tubes are in use; air is charged with ozone by means of these and is passed up dripping towers, down which the water trickles, with the result that the water is completely sterilised as regards all deleterious organisms. At Schierstein the capacity of the plant is nearly 50,000 gallons per hour, and the power required is 50 H.P., of which, however, only 27 is used for ozonising, the remainder serves for pumping, etc. The pressure used is 8,000 volts. The working cost is in all from 3½d. to 4½d. per 1,000 gallons.

By the Jaruti process water is electrolysed to give pure hydrogen and oxygen, consuming 115 k.w.-hrs. per 1,000 cubic feet. A solution of caustic soda is used, with a perforated iron diaphragm to separate the gases.

At Stangfjorden, in Sweden, the Jebsen system is used for the manufacture of briquettes from peat. The latter is carbonised by heating with the electric current, derived from water power, and the tarry by-products are recovered.

The production of nitric acid from the atmosphere has long been the subject of experimental research; it is now in active operation at Niagara Falls, where by means of electric discharges at extremely high pressures and frequencies the nitrogen and oxygen are caused to combine. The same subject has been dealt with on the Continent, where a return of 52 to 55 grams of nitric acid per kilowatt-hour has been obtained, using a current of 0·05 ampere at 50,000 volts, and 6,000 to 10,000 cycles per second. As Sir William Crookes has shown, the fixation of atmospheric nitrogen may in the distant future have a

most important bearing upon the existence of the vast population of the earth, when natural sources fail to furnish an adequate supply of food.

In connection with this subject, the synthesis of sugars by the electrolysis of carbonic acid, ammonium, phosphate, etc., which has been accomplished by Walther, is of no little interest.

The extraordinary potency of electrolysis and the electric furnace in chemical and metallurgical processes has been most largely made use of in America, which is, in fact, the electro-chemical headquarters of the world. The various works which derive their power from Niagara Falls are producing caustic soda, chloride of lime, carbide of calcium, chlorate of potash, sodium and sodium peroxide, sodium cyanide, baryta, phosphorus, nitric acid, lead, carborundum, graphite, corundum, etc. A single American concern is producing 4,500 tons of aluminium per annum, while the United States produces 278,860 tons of electrolytic copper per annum, no less than 86·5 per cent. of the world's output. Siloxicon, a highly refractory compound of silicon, carbon and oxygen, is one of the latest products of Niagara. The electrolytic rectifier, which depends upon the peculiar properties of aluminium in an electrolytic cell, is a device which will have many applications, especially since it has been so arranged as to ingeniously utilise both positive and negative waves of an alternating current.

One of the most important branches of electro-chemistry is that which relates to secondary batteries, and, in spite of the immense amount of work which has been done in this direction in the past, remarkable progress has been made of late. The most notable invention in this department is the Edison nickel-iron cell, which appears to be on the verge of adoption on a commercial scale. Elaborate machinery has been designed and constructed at great cost for the rapid manufacture of the cells, and trial cells have been in the hands of European experts for many months, while complete sets have been exhaustively tested in America and England. There seems to be no question that the cells have fulfilled the claims made for them, and that their introduction in quantity will give an immense impetus to the electric automobile industry, and even to accumulator traction in general. The cleanliness, capacity, and seeming indestructibility of the cells, joined to their highly perfected mechanical construction, render them admirably adapted to automobilism, and the stated ability to charge them with 75 per cent. of their full capacity in one hour is a feature of the first importance.

Other cells have been brought forward, notably the Elieson cell, which is an improved lead plate cell, with the property of enduring remarkably high rates of charge and discharge without injury, and the "N.S." (Niblett Solid) cell, in which the whole of the positive and negative elements are packed tightly in a container. Each of these has meritorious features, but whether they will stand the test of time cannot yet be decided.

Besides the foregoing examples, a vast amount of work is being done in every branch of electro-chemistry, and the recent formation of the Faraday Society, admirably named, to further the interests of the science and industry in this country—long after the birth of similar

societies abroad, it is true—can well be included as one of the most important and fruitful "recent developments" in the electrical world.

I will now bring this address to a close, as I began it, with a reference to the growth of this Institution.

In my opening remarks I omitted an observation which I should have made concerning this growth, and that was in reference to the source from which our members are drawn. Had not a great wave of educational fervour passed over this country some twenty years ago, had not the establishment of technical institutes all over the country taken place, had not Lord Kelvin, and others, educated their pupils in a way which best fitted them for the position of efficient teachers in these technical colleges, our Institution would not have attained its present importance, and the posts filled by many of its members would, perforce, have been filled by the better educated foreigner. It is a great advantage to the taught that their teachers should be concerned with the practical side of the subject they treat, and this in itself is a justification for those who teach, being members of our Institution and taking an active part in its management. Teaching from text-books which are written on an undeveloped science causes the student to learn many things that he has to unlearn, and launches him into the world full of information which may have been abandoned altogether, or is at least five or six years old. If the teachers are in touch with everyday practice the taught profit immensely, and leave their colleges with knowledge which, although it may later require modifying, has at any rate the advantage of being the knowledge of the day. I believe the Electrical Industry in this country is almost entirely in the hands of electrical engineers educated in England. Can this be said of the Chemical Industry? I doubt it, and presume that it is because the latter is a much older science, and has not been favoured in possessing in this country so many educational advantages as are offered to those engaged in the electrical industry. It certainly has not, as a general body, had teachers with the same practical experience, although there are undoubted signs that the younger generation is being better taught. To cite one instance in my personal knowledge, out of the many which might be selected: I remember my father introducing into Scotland, for the purposes of calico printing and dyeing, the use of certain coal-tar dyes, the employment of which had just been made practicable by Mr. W. H. Perkin. Forty-five years have elapsed since then; and although Great Britain has practically been the home of the raw material and one of the greatest consumers of these products, yet, through the application of greater knowledge and skill, Germany to-day furnishes our printers and dyers with the greater proportion of their requirements. We are being beaten in a race in which the foreigner is handicapped. Is this due to the natural incapacity of the Englishman, or is it due to the want of the opportunities which his foreign competitor possesses? Despite the opinion recently expressed by Professor Karl Pearson, I like to accept the latter explanation, although, given the opportunities, we must always bear in mind that a chemist's work is laborious in the extreme, and this may not as a rule satisfy the ordinary class of English student. In adopting this illustra-

tion, I do not wish to be misunderstood. I have no intention of implying, and it would be foolish to imply, that this country does not possess chemical knowledge of the very highest order, as witness the number of distinguished men whom we know by name, and the work they have done, and also the large number of chemical works established in the London, Manchester, Glasgow and other districts. I also fully recognise that the chemical industry cannot be fairly compared with the electrical industry, as it occupies a much wider field, and is a much more difficult subject to master. I use the illustration, as I do not believe the mass of the people engaged in the industry have placed at their disposal sufficient opportunity for proper instruction, or for acquiring knowledge, as is the case in Germany and some other countries.

With wisdom, we in this country open our arms to the skilled man of other countries, and through his skill we can, in certain directions, maintain supremacy in some of our productions. The pity of it is that we have not amongst our own countrymen men of equal education and skill. One may say that the electrical industry is also suffering, and that the signs of it are the large importation of American and German machinery into this country at the present time; but I venture to disagree. Americans and Germans are doubtless appearing on our markets, and, in many cases, owing to greater skill in manufacture; but the financial side of the question has a great deal to do with their incursion, and especially is this so with their competition in our Colonies and in non-manufacturing countries.

We must, as a policy, continue to welcome all comers, but while so doing we should equip ourselves so that by sheer skill and ability we may conquer in the end. The equipment we require is, every one now admits, technical education, and this we are developing in all directions. The electrical engineers as a class are better equipped than any other class I know of, thanks to the teaching received in our technical institutions from very capable men, some of whom we are proud to see numbered among the Past-Presidents of this Institution.

During the recess, several powerful advocacies for the furnishing of greater educational facilities to the students of this country have been published, and it is gratifying to see that these publications were made in a manner to bring them before every one who cares to read them. Sir Norman Lockyer, in his presidential address to the British Association Meeting at Stockport, made a stirring appeal, which must sink into the soul of every thinking man who has the welfare of his country at heart. Sir William Abney, as chairman of Section L.—Educational Science—placed before the public what has been done since 1853 by the Science and Art Department with the small amount of funds at their disposal. Professor Meldola's lecture, delivered in August last at Oxford on Chemical Industry and Research, should also be mentioned, as it deserves careful reading.

Opportunely, Professor H. E. Armstrong has just had published by Macmillan and Co. a collection of his writings on Education. Sir William Ramsay, the President of the Society of Chemical Industry, and many others who are interested in industrial development, are

actively forwarding the cause; and it is to be hoped that some good may be evolved from the atmosphere of public interest which has been created, and that we may thus eventually find the men of this country as well furnished as their foreign competitors with the necessary knowledge, and with the means of applying it in investigation. Our Past-President, Dr. John Perry, informs me that there is under consideration the formation of a Science Guild, whose fundamental object will be the encouragement of the application of scientific principles to industrial and general purposes. We must all hope those engaged in the matter will succeed in founding this Guild, as there doubtless exists a blank which it can fill.

I am glad to see some of our members—notably my predecessor, Mr. Swinburne, and our Honorary Member and Past-President, Mr. Swan—are interesting themselves in the formation of the Electro-Chemical Society, to which I have already referred; and I am sure we all wish them every success in their effort to specialise in Great Britain this very important subject.

For the future development of the usefulness of the Institution there appears to me to be one matter worthy of our utmost attention. The Institution membership extends all over England and the Colonies, and we have found it a useful addition to our constitution to establish Local Sections in different centres. Since these Sections have been formed, many valuable contributions have been incorporated in the Journal of the Institution which might not have appeared there, had the opportunity of having a meeting-place in the author's neighbourhood been absent, and had there not existed an organised assembly to discuss the subject submitted by him. The Local Sections are growing, and must by the nature of things increase in importance. The development of the electrical industry in the provinces must advance with greater strides than in London, where manufacturers are hampered by high local rates, and sometimes obstructive legislation, which appears to be a necessity in our large metropolis, and which is, fortunately, not so essential in smaller communities. Again, in the neighbourhood of London the cost of raw material is appreciably higher; fuel is also higher, and the charges for the transport of the finished goods to their destination handicaps the London manufacturer. These, in addition to the higher scale of wages paid, are fast driving manufacturers into the provinces. Such a migration, from a general point of view, is perhaps advantageous; but it indirectly affects the Institution in a way which is not of advantage to the Central Body. If the migration continues to the same extent as took place in the case of London shipbuilding many years ago, the centre of production, so to speak, of the electrical industry will gradually gravitate northwards, and nothing but consumers will be left in the metropolis. Many of our ablest members are already in the provinces, and it is quite a question for the Institution to consider whether the day is not fast approaching when we should extend our system of decentralisation. Is it not time that we should consider the establishing of a Local Section in London, similar in all respects to the Local Sections we have in Birmingham, Dublin, Glasgow, Leeds, Manchester and Newcastle? In this new Local

Section papers affecting London could be read, and be published or not in the Journal of the Institution in the same manner as papers in the other local sections are dealt with. London would continue to be the headquarters of the Institution, and Institution meetings could be held, say, four times a year. At these, papers of general interest could be contributed. If any such scheme as this were adopted, the constitution of the Council of the Institution would be somewhat affected. The chairman and committee of the London Local Section would, of course, be all London men, but the Institution would have a larger field from which to select its President and Council, as men who have their business in the provinces, and who cannot spare the time to attend the present numerous Council and Institution meetings, might be able to attend the less numerous meetings which would be the outcome of some such rearrangement.

In conclusion, I must thank you for the kind tolerance with which you have received the remarks that I have had the pleasure of submitting for your acceptance.

Professor Ayrton.

Professor W. E. AYRTON: On the last occasion that we had the pleasure, as a body, of meeting our President, it was in another hall, to listen, at his generous invitation, to the melody of instruments and to the music of the voice. To-night again it is a voice that has entranced us, the voice of our President, which, while singing the praises of what is good in our country relating to electricity, has warned us of what we ought to improve. I am sure we must all join with him in hoping that Westminster may see the rising of a Temple of Engineering. But I fear that the history of that project will be the history of so many others. England originates the idea, America adopts and develops it, and then later on England re-imports it. More than twenty years ago the late Sir William Siemens proposed, as our President has said, that there should be a temple in Westminster for applied science, corresponding with Burlington House for pure science, and he was generous enough to offer to start a subscription with £10,000. During my visit this autumn to America, when serving with the Moseley Educational Commission, I learned that the liberality of Carnegie had made that idea a *fait accompli* in New York for the four important Engineering Societies there. There is to be a great hall, and the land and the money are provided. Now, on the other hand, when those of you who to-night are young will be bemoaning your lost youth, and those of us whose heads are already grey will be taking no further interest in the proceedings, England will re-import this idea, with the privilege of paying a duty under a Chamberlain protective tariff.

The reference of your President to submarine telegraphy was to me pathetic, for it brought back to my mind the image of many past-presidents, now dead, sitting in that chair, men who made England distinctly first in the manufacturing and laying of submarine cables, an industry, I am happy to say, in which England, thanks to men like your President, is still first. I ask you to give your President the most warm vote of thanks you possibly can for the instructive and interesting address he has given us, and to show your desire that, with his per-

Professor Ayrton.

mission, the address be printed in the Journal of Proceedings of the Institution.

Mr. Gavey.

Mr. J. GAVEY, C.B.: It is with very great pleasure that I rise to second the resolution of thanks to our esteemed President. I well remember in the early days of this Institution when he and I frequently attended its meetings together, when its membership did not number as many scores as it now numbers hundreds, and at a time when the range of electrical industry was practically comprised in the one word "telegraphy." How far that range has extended, to what an extent we, as electrical engineers, now influence the welfare, for good or for evil, of the human race is well illustrated, I think, by your President's address; and if you will measure the amount of space he gives to telegraphy and that which he gives to the immensely widened possibilities of electrical engineering, you can judge as well as I what that growth has been. Seeing that our friend the President was one of the pioneers in the early days of the electrical industry, it is with much gratification that I see him sitting in this chair to-night, and it is with the utmost pleasure that I second the resolution of thanks to him for the charming address he has given us, and in doing so beg leave to ask that with his permission the address be published and distributed to the members.

The resolution was put to the meeting by Professor Ayrton, and carried with acclamation.

The President.

The PRESIDENT: I thank you very much for your sympathetic listening to what I had to say; it has been a great pleasure to me to be able to keep your attention for so long a time.

The Three Hundred and Ninety-seventh Ordinary General Meeting of the Institution was held at the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, November 26, 1903—Mr. ROBERT KAYE GRAY, President, in the chair.

The minutes of the Special General Meeting held on July 31, 1903, and of the Ordinary General Meeting held on November 12, 1903, were taken as read, and confirmed.

The names of new candidates for election into the Institution were taken as read, and it was ordered that these names should be suspended in the Library of the Institution.

The following list of transfers was published as having been approved by the Council :—

From the class of Associates to that of Associate Members—

Henry Lionel Howard.

From the class of Students to that of Associates—

Harold William Sextus Davey.

Messrs. E. J. Howell and A. Russell were appointed scrutineers of the ballot for the election of new members.

Donations to the Library were announced as having been received since the last meeting from The Associazione Elettrotecnica Italiana, the Engineering Standards Committee, the Patent Office Library, and Mr. W. R. Twelvetrees, to all of whom the thanks of the meeting were duly accorded.

The PRESIDENT : Before proceeding with the ordinary business of the evening, I would like to report that a deputation from the Institution went to Windsor Castle to present to the King of Italy the Address which the Institution had prepared. I do not propose to read it to you now, but it will be printed in the Journal.* After the audience, the

* The following is the text of the Address :—

To His Majesty Victor Emmanuel III., King of Italy.

May it please Your Majesty,—

The Institution of Electrical Engineers of Great Britain, having in the Spring of the present year rendered homage at the tomb of the illustrious physicist, Alessandro Volta, and having visited the Electrical Railways, Power Stations and Works, which form so noble a monument to Italian enterprise of to-day, humbly beg permission to avail themselves of the present opportunity and to lay before Your Majesty an expression of their recognition of the courteous and generous hospitality accorded to the Members of this Institution, not only by their sister Society, the Associazione Elettrotecnica Italiana, and

deputation telegraphed to the Associazione Elettrotecnica Italiana, both to the Central Body in Rome and to the local section in Milan, to acquaint them of the fact, and Professor Ascoli replied as follows from Rome: "Most sensible to the feelings that inspired your kind telegram. I thank the Institution of Electrical Engineers for this new proof of sympathy, and return most hearty greetings in the name of the Associazione Elettrotecnica Italiana." Mr. Bertini and Mr. Semenza, the President and the Secretary of the Milan section, telegraphed saying, "Homage added by Institution Electrical Engineers to enthusiastic reception of our King by all England, was learned with grateful feelings by the Milan section of the Associazione Elettrotecnica Italiana, as a new token of friendship binding the scientific bodies of the two countries."

There is another announcement I have to make, and I do so with great regret—Colonel Pescetto, the Hon. Secretary in Italy of the Institution, has died. Colonel Pescetto was known to a great many of us, and in addition to possessing considerable technical knowledge, he was an exceedingly gentle, kind-hearted man. Those of us who can remember the manner in which he assisted us during our visit to Italy will feel that they have lost one whom they had learned to regard as a personal friend.

Professor Threlfall will now read his paper.

THE TESTING OF ELECTRIC GENERATORS BY AIR CALORIMETRY.

By RICHARD THRELFALL, M.A., F.R.S., Member.

In his interesting paper on Recent Electrical Design, Mr. W. B. Esson mentioned the uncertainties attending the testing of alternators (*Trans. Elec. Eng.*, vol. 32, p. 351). This uncertainty has been felt by many people as well as Mr. Esson, and may be said to constitute a serious difficulty to those who make or use large alternators. It has

by Electrical Engineers generally, but also by the various Municipalities and Corporations of the districts visited by them. The Members of the Institution who were fortunate enough to visit Your Majesty's dominions will never forget the genial kindness of their reception by the distinguished Engineers and others whom it was their privilege to meet. During Your Majesty's presence in England the President, Council, and Members of this Institution respectfully tender an assurance of their devotion to the Sovereign of a nation for whom they entertain feelings of the highest respect, admiration, and affection. We ever pray that the friendship and good-feeling between the two countries, of which the warmth of our reception in Italy gave convincing proof, may continually grow in intensity, and that Your Majesty may long be spared to guide the destinies of a nation to whom the people of this country are united by the bonds of an inalienable sympathy.

Given under our hand and seal at Westminster this second day of November, 1903.

ROBERT KAYE GRAY, *President.*
C. E. WEBBER, *Member of Council.*
WALTER G. MCMILLAN, *Secretary.*

been the good fortune of the writer to succeed in working out a simple and practical way out of the difficulty by means of air calorimetry.

Two years ago an occasion arose where the testing of some large alternators for efficiency was a matter of necessity, and it was practically impossible to measure the brake horse-power developed by the engine under running conditions, owing to the field magnets being built upon the flywheel and to other structural peculiarities.

The only alternative at first appeared to be running two of the machines as generator and motor respectively, but their relative fixed positions in the engine-house prevented anything of this kind being attempted.

It appeared to the writer that only one course was open to him, viz., to enclose the alternators in a non-conducting casing, and to pump air through the system at a measured rate. Assuming that means could be found for the rapid and accurate measurement of a large current of air it would be only necessary to ascertain the temperature of the air on entering and leaving the system, in order to have all the data necessary for a computation as to the rate of dissipation of energy in the alternator. There would of course be corrections for heat entering or leaving the system otherwise than by means of the air current, but simple means were found for reducing this correction practically to zero. Assuming that M kilograms of air of specific heat σ pass through the system per second, being raised in temperature from t° to θ° centigrade in the process, and that no heat is gained or lost except from the alternator, it is clear that heat to the extent

$$M\,\sigma\,(\theta - t) = H'$$

represents the rate at which power is being wasted in kilogram-calories.

Let P represent the rate of external working of the engine in kilowatts, and P^{1} the power delivered by the generator as measured electrically also in kilowatts. Then the efficiency of the generator is

$$E = \frac{P^{1}}{P}$$

Let H be the rate at which energy is carried out of the system by the air current, stated also in kilowatts—

Then—

$$P^{1} + H = P,$$

and—

$$E = \frac{P^{1}}{P^{1} + H}.$$

This assumes that the generator does not "radiate" like a wireless telegraph transmitter.

P^{1} can of course be exactly measured, and it will be shown that H also can be measured with quite sufficient accuracy.

It is important to notice that the subject of measurement H is the actual loss in the generator from all causes, and the method has the advantage of the directness of the well-known Hopkinson test. Also it is to be observed that if the efficiency is anything like 90 per cent. H is only one-ninth part of P^{1}, and an error in the estimate of H becomes

of less and less importance as the efficiency rises. For instance, if H were 10 per cent. in error the efficiency would only be wrong by a little over 1 per cent. in the case where the actual efficiency was really 90 per cent. In practice the errors in estimating H are of the order of 2 or 3 per cent.

Now it is shown by J. S. Ames (*Rapports présentés au Congrès International de Physique*, Paris, 1900, vol. i., p. 204), that the most probable value for the gramme calorie in ergs is $4{\cdot}181 \times 10^7$ at 20° C. on the nitrogen scale, and though it is not pretended that in what follows it matters whether we use this number or the familiar 4·2—still it would be ungrateful to the physicists to ignore their labours by adopting the latter value.

The specific heat of dry air at constant pressure is now known not to be absolutely constant and independent of pressure and temperature, but we may for the present purpose take Regnault's value of 0·2375 as amply accurate enough at ordinary temperatures and pressures. The effect of moisture in the air will be considered later.

The energy gained by a kilogram of dry air in rising by 1° C. at constant pressure under standard conditions is therefore very nearly $9{\cdot}93 \times 10^9$ ergs, or 993 watts if the gain of temperature is a degree per second. The round relation of 1 kilowatt heating 1 kilogram of air 1 degree per second is obviously convenient. It is also convenient to set down that 1 kilogram of dry air measures nearly 773 litres, or 0·773 cubic metres, under standard conditions: and 1 cubic metre weighs nearly 1·293 kilos. Consequently 1 cubic metre of air heated 1° C. per second requires 1·277 kilowatts.

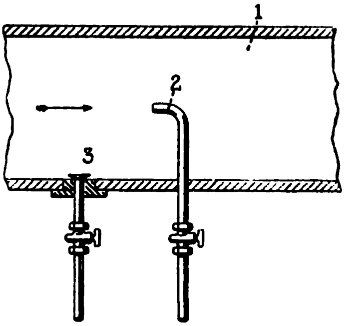


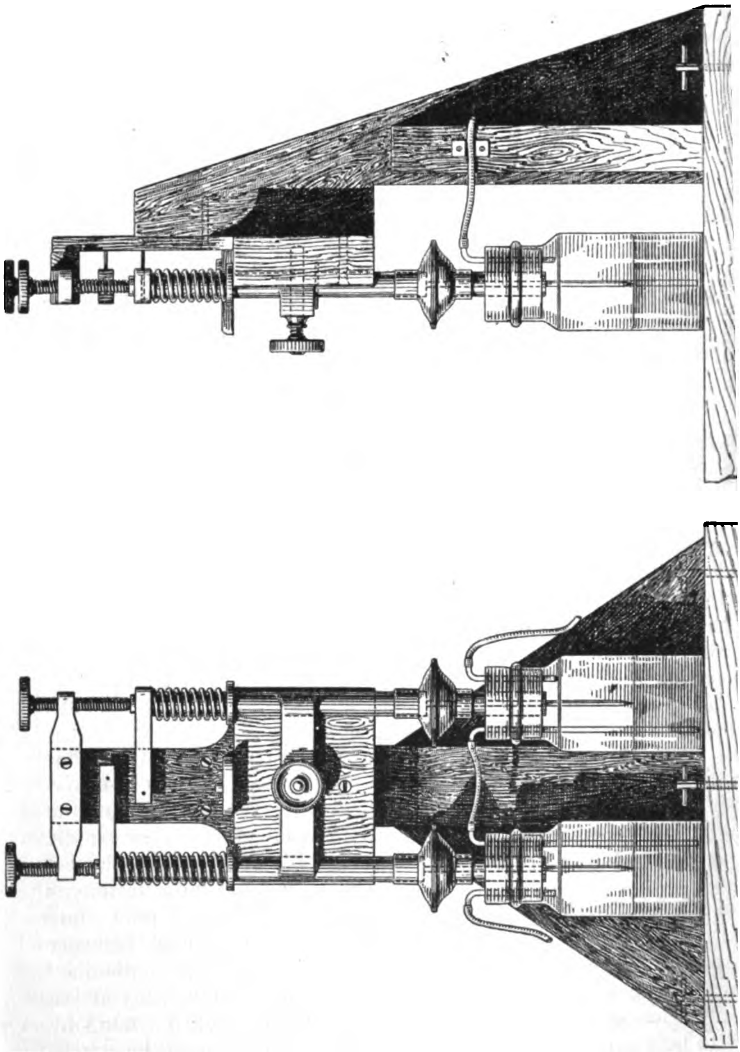
FIG. 1.

The main difficulty in regard to the experiment consists in the measurement of the air current, and therefore this matter was first investigated. The investigations made originally with the object of carrying out the tests described in this paper showed that the measurement of large currents of air can easily be made so as to give results within 2 per cent. of the true value. The measurement of air velocity is made by means of what is known as the Pitot tube, which is merely a tube bent in such a manner as to receive the full force of the stream of air on its open end. In consequence of some of the impinging air losing momentum by the impact, a certain degree of pressure is set up within the Pitot tube if the latter be closed except where it faces the stream, and this pressure will be referred to as the velocity pressure. The writer has been able to show that almost exactly half the momentum of the impinging air is destroyed by the quiescent air in the Pitot tube, and in consequence a velocity pressure appears almost exactly equal to

$$\rho\frac{V^2}{2} \text{ dynes per square centimetre,}$$

where ρ is the density of the air in grammes per cubic centimetre and V its velocity in centimetres per second. In general the mean pressure of the air stream is above or below the pressure of the external air, and consequently it is necessary to insert another tube in the air current which shall be subject merely to the static pressure of the stream. This is not very easy to do, but Heenan and Gilbert (*Proc. C.E.*, vol. 123, p. 272) have shown that if we use a tube provided with a wide flange at the mouth, the tube being so placed that the air slides past the flange, we do in fact obtain the pressure sought. The diagram (Fig. 1) will make the arrangement clear. The same result is practically attained if a small hole be bored through the side of the pipe carrying the air current and an external connection be made to the manometer. In practice a hole is drilled and tapped in the side of the pipe, and into this hole a small pipe is screwed—care being taken that it does not project inwards beyond the inner surface of the main pipe. It is tempting but fatal to accuracy to use a side gauge consisting merely of a bit of pipe across the end of which the air stream blows. This gives rise to a suction which may rise to nearly the Pitot tube velocity pressure (with sign reversed), but unfortunately no two pipes will give the same suction. The thinner the walls of the pipe the greater the effect. Many attempts have been made from time to time to utilise the suction as well as the pressure, and it is believed that the discredit which has been thrown on the Pitot method of measuring the velocity of fluids is almost or entirely due to the uncertainties in the suction effect of a wrongly designed side gauge, which do not appear to have been sufficiently considered. The Pitot tube itself is deserving of the rank of an instrument of precision, simple though it is in construction.

It is necessary to have a reliable manometer in order to obtain the value of the pressure difference with accuracy. A form of instrument which has been employed by the writer is figured (Fig. 2); it can be relied upon absolutely to within 0·01 mm. of water pressure. It will be seen that it consists essentially of two bottles containing coloured water—the bottles are connected by a syphon, and the air space of each bottle is put in communication with its appropriate tube. The readings are taken by setting a pair of needle points just to touch the liquid surface, and then measuring how they differ in level by micrometer screws, or by callipering suitable jaws. Each needle point is carried by a shaft working on geometrical principles, and the result is that the insidious errors which always accompany attempts to read off small distances through walls of unworked glass tubes are got rid of. A convenient supplementary apparatus is a small multiplying pressure gauge, in which the motion of a float or bell is used to operate a finger moving round a dial. The dial is divided in such a manner that the square roots of the pressure differences can be at once read off. Such instruments, if carefully made, work remarkably well, and are very useful during a trial from the ease with which they are read. It is important to have as steady a stream of air as possible, for if the



fluctuations are rapid as compared with the "time constant" of the manometer, the latter will average up the pressure differences, giving the arithmetical mean pressure. It is clear, however, that what is required is the mean of the square roots of the pressure differences, as was pointed out by M. A. Rateau (*Ann. des Mines*, S9, vol. 13, p. 331, 1898). It has already been stated that if exactly half the momentum of the air impinging on the air at rest in the Pitot tube is destroyed, we should get a pressure of—

$$p = \rho \frac{V^2}{2},$$

or $$V = \sqrt{\frac{2p}{\rho}},$$

or $$V = 1 \cdot 414 \sqrt{\frac{p}{\rho}}.$$

The result of a very large number of measurements undertaken for the purpose of fixing on a suitable constant has been to show that in practice the relation is more nearly

$$V = 1 \cdot 377 \sqrt{\frac{p}{\rho}},$$

p being in dynes per square centimetre, ρ in grammes per cubic centimetre, and V in centimetres per second. The reason of this difference is discussed elsewhere. If we take g at 982, p as being measured in millimetres of water, and ρ the density of dry air at 0° C., we can convert the above into a more easily applied formula.

$$\begin{aligned} V &= 1 \cdot 377 \sqrt{\frac{98 \cdot 2}{\cdot 001293}} \cdot \sqrt{p}. \\ &= 379 \cdot 4 \sqrt{p} \text{ centm per sec.} \\ &= 747 \cdot 0 \sqrt{p} \text{ feet per min.} \\ &= 12 \cdot 45 \sqrt{p} \text{ feet per sec.} \end{aligned}$$

The ascertainment of the velocity of air at a certain point in the cross section of a pipe is, however, only the first step towards discovering the delivery in cubic feet per second, say. In order to find the delivery we must know the velocity at every point of the cross section. Now in *Mémoires de l'Académie des Sciences*, vol. 15, 1858, Darcy showed that in the case of water in long pipes in which the fluid velocity is symmetrically distributed with regard to the centre of the pipe, there is a certain circle, the locus of points at which the velocity of the water has a mean value—such that the delivery of the pipe can be obtained by multiplying the area of cross section by the fluid velocity at the circumference of this circle. The radius of the circle is found by Darcy to be given by the expression in terms of the radius of the pipe R.

$$r = \left(\frac{4}{7}\right)^{\frac{2}{3}} R = \cdot 689 \text{ R}.$$

This is obviously nearly $\frac{2}{3}$ R, and is no doubt the origin of the common opinion that if a Pitot tube be inserted to a distance of one-

third the tube radius from one side, the mean velocity will be measured. In no case within the writer's experience is this actually the case when we come to deal with air. If a fan be used, then in general the flow is for a distance of many diameters of the pipe—usually far from symmetrical. This is true even when the fan blows first into a box (from which the pipe takes its supply), which is very large compared with the diameter of the pipe. By using baffles of

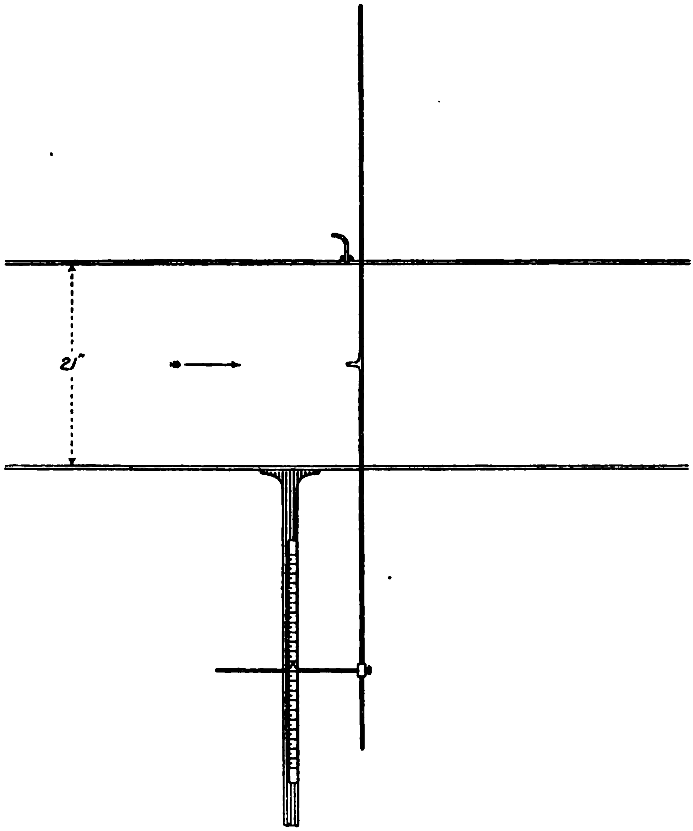


FIG. 3.

various shapes between the fan and the measuring point in the pipe it is usually possible to make the distribution symmetrical, but at the expense of a greatly increased resistance to the flow of air. Amongst other things tried, the writer has used very open muslin—mosquito netting, in fact—and this gives a very uniform, though arbitrary velocity distribution. M. Marey has made use of the same artifice. On the whole, the only safe way is to have a measuring pipe made up of some light material, such as tin or mill-board—at least 10 to 20 diameters long, though it may be made in several pieces if convenient,

each piece being a trifle coned to fit into the next. Armed with such a pipe, the first thing to do is to start the fan at a convenient speed, and to measure the velocity distribution at several points across a diameter by the Pitot tube. The Fig. 3 shows the arrangement adopted

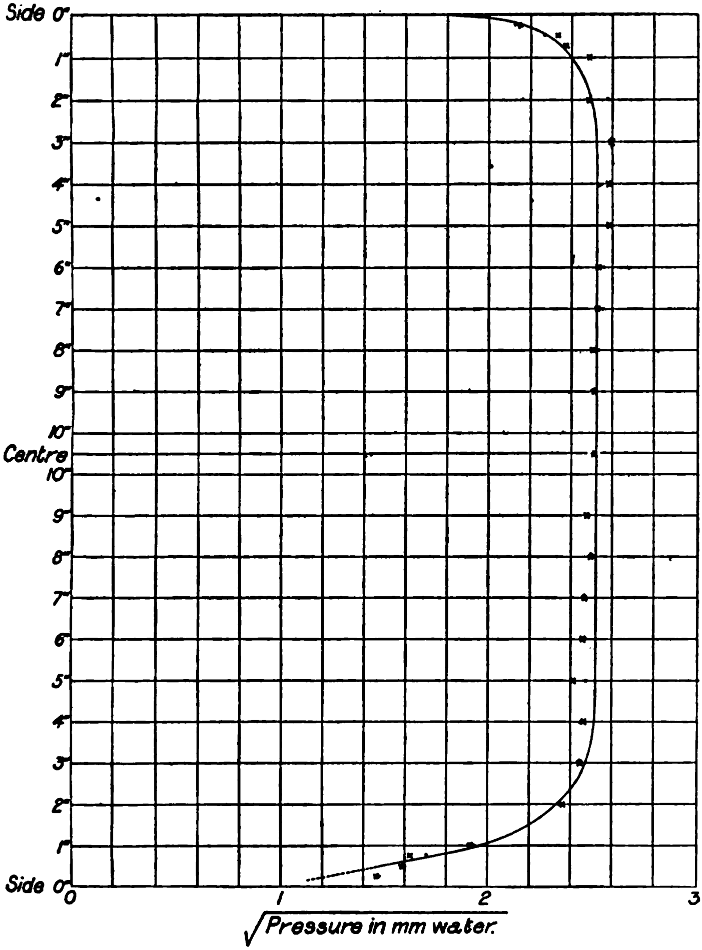


FIG. 4.

for this purpose. The chief difficulty is in keeping the fan going at a sufficiently regular velocity, and a convenient way of testing this for the purpose of the experiment is to set up a second Pitot tube at some point in the measuring pipe, so that its tip is at the centre of the pipe.

This subsidiary gauge, consisting of the Pitot tube and side gauge, is connected to a multiplying pressure gauge, as already described, and the system forms precisely a pneumatic ammeter, and shows if the current of air fluctuates at all. We have generally used the phrase "stream gauge" to indicate such an arrangement. If the velocity of the stream is kept constant by following the indications of the stream gauge, the calibration of the stream across a diameter of the pipe is easily carried out. In general, it is not necessary to investigate more than one diameter, but the condition is that the velocity distribution must not be too unsymmetrical. Fig. 4 shows a distribution curve actually obtained on one diameter, and it is not desirable to have the distribution more unsymmetrical than this. In selecting points for observation, it must be remembered that as we move outwards from the centre the observations become of greater and greater importance, so that the points of observation are taken closer together at the outer parts of the stream.

The observations being made, they are plotted as square roots of the pressure difference—conveniently in millimetres of water, as abscissæ—the Pitot gauge positions being taken as ordinates. From the resulting curve pairs of points are selected at opposite sides of the centre, and the area is imagined broken up into annular spaces, of which the points occupy the centre of section. The area of each annulus is easily calculated and multiplied by the mean of the two corresponding square roots of pressures. These quantities are all obviously proportional to the delivery of air across the annulus they represent, and the sum only requires to be multiplied by the constant—*e.g.*, 12·53 for cubic feet per second of air at 0° C.—in order to obtain the delivery. It is convenient to ascertain the mean velocity from this result by dividing the delivery by the area of the cross section of the pipe. The position of mean velocity may then be obtained from the curve; and also the ratio of the mean to the central velocity evaluated. The latter is generally about 0·9, but it may be anything from 0·75 to 0·95, according to the length of pipe, mode of blowing, etc. If the fan be used to suck air through the apparatus, and the measurement of flow be made on the inlet pipe, the velocity distribution is generally more simple, but very often this course is otherwise inconvenient.

The first question which will occur to any one thinking of the matter is the following: How does the velocity distribution vary if the velocity of the air stream changes as a whole? The writer has carried out experiments for nearly two years on this subject—which is, of course, vital—and the conclusion is that practically speaking there is no variation at all. That is to say, if the apparatus be once put together, the fan can be driven fast or slow without making any appreciable change in the velocity distribution. The following table, Table I., which gives the results of some careful experiments on a 6-inch and a 12-inch pipe, will show what sort of variation does actually occur; it is otherwise without significance for the present purpose.

TABLE I.

Distribution of Velocity at various Velocities.

Series.	Maximum Velocity in Feet per Minute.	Mean Velocity / Maximum Velocity.	Position of Circle of Mean Velocity in Terms of the Radius of Pipe Section measured from Centre.	Diameter of Pipe.	Remarks.
1	666·72	·8845	·768	6	Air current maintained by fan.
2	1,666·9	·8623	·766	6	
3	2,675·0	·8742	·773	6	
4	3,642·0	·8750	·765	6	
5	1,714·2	·8872	·773	12	Air current maintained by fan.
6	2,594·4	·8990	·801	12	
7	2,771·5	·8861	·773	12	
8	1,319·4	·8066	·737	6	Air current maintained by fall of gas-holder.
9	2,472·6	·7900	·721	6	
10	2,406·3	·8148	·725	6	
11	325·08	·9168	·863	6	Air current maintained by fan blowing through a pipe provided with a baffle.
12	1,692·2	·9132	·798	6	
13	2,428·8	·9076	·796	6	
14	2,664·0	·9054	·793	6	

In experiments 8, 9, and 10, the delivery of air was separately estimated by timing the fall of the holder. The delivery for 6 feet of this fall is as follows, and may be compared with delivery measured by the Pitot tube and manometer, and deduced from the formula.

Delivery by Observation of Gas-holder.	Delivery deduced from Gauge Readings and Calibration of Pipe by Formula.	Error of Gauge Measurements, if Timing of Holder be taken as Correct.	Mean Error, assuming that the Holder Measurement is Correct.
1,881·3	1,889·0	0·94 % too high.	
1,880·0	1,835·5	2·9 % too low.	1 % too low.
1,880·0	1,866·0	1·28 % too high.	

If the apparatus be altered by altering the relative position of the measuring pipe and fan, then a new calibration must be made. Described at length, as in what precedes, the work of preparation appears formidable. It is not so in reality, for when a little practice has been obtained the observations are quickly and easily taken. During a test of dynamo efficiency, of course it is only necessary to observe the stream gauge and keep the stream as steady as possible according to its indications, the absolute manometer being used from time to time as a check. The density of the air can easily be calculated from available tables—*e.g.*, Glaisher's Hygrometrical tables.

In order to illustrate the practice of measuring the flow of air in a

pipe, a complete set of observations and calculations will now be submitted. These observations formed part of an actual test on the efficiency of a certain 300-k.w. alternator.

TABLE II.

Distribution of Velocity in Pipe 21 Inches Internal Diameter.

Distance of Pitot Gauge from Centre of Pipe. Inches.	Manometer Pressure Difference in Mm. of Water. Left of Centre.	Right of Centre.
0 (Centre)	2·516	2·512
1·5	2·518	2·488
2·5	2·536	2·506
3·5	2·5515	2·474
4·5	2·559	2·470
5·5	2·577	2·480
6·5	2·596	2·458
7·5	2·596	2·427
8·5	2·573	2·349
9·5	2·456	1·939
9·75	2·362	1·703
10·0	2·263	1·600
10·25	2·126	1·476

Delivery of Air by 21-Inch Pipe from Observations of Manometer Pressure Difference, the Square Roots of which were Plotted as Shown in Curve 1, Page 35.

Specification of Shells Measured in Inches from Side of Pipe.	Pressure Difference from Curve. Right of Centre.	Pressure Difference from Curve. Left of Centre.	Mean of Pressure Differences.	Area of Shells in Square Feet.	Area of Shells × (Pressure Difference) ½.
10·5 — 5·0	2·528	2·528	2·528	·6597	1·667
5 — 4	2·520	2·528	2·524	·2615	·660
4 — 3	2·500	2·526	2·513	·3053	·767
3 — 2	2·420	2·515	2·467	·3487	·860
2 — 1	2·200	2·460	2·330	·3929	·915
1 — ·5	1·730	2·350	2·040	·2135	·435
·5 — side.	1·220	2·160	1·690	·2237	·378
				2·4054	5·684

$$\sqrt{\frac{\text{Maximum pressure}}{\text{difference}}} \times \text{Total area} = 2{\cdot}528 \times 2{\cdot}4054,$$
$$= 6{\cdot}0812.$$

$$\frac{\text{Mean velocity}}{\text{Maximum velocity}} = \frac{5{\cdot}684}{6{\cdot}0812} = 0{\cdot}935.$$

Calculation of air delivered per minute by pipe, 21 inches internal diameter: the maximum pressure difference being in this case 6·29 mm. of water. Barometer, 748·5 mm. at 59° F.—correction neglected. Temperature of air at intake: dry bulb, 58·83° F. = 14·9° C.; wet bulb, 55·70° F. = 13·16° C. Humidity, 80 per cent. from tables: corresponding pressure of aqueous vapour, 10·1 mm.

Density of mixture of air and water vapour at temperature of gauges 34° C. and 748·5 mm. pressure, ·001127 grammes per cc.

If the humidity had been neglected, the density would have been more by 0·4 per cent., which is without significance.

Maximum and central pressure difference during a certain trial was 6·29 mm. of water. Hence maximum velocity in centimetres per second was—

$$= 1{\cdot}377 \sqrt{\frac{6{\cdot}29 \times 98{\cdot}12}{{\cdot}001127}}$$
$$= 1{,}019 \text{ cms. per second,}$$
$$= 33{\cdot}43 \text{ feet per second,}$$

and average velocity—

$$= 33{\cdot}43 \times {\cdot}935,$$
$$= 31{\cdot}26 \text{ feet per second.}$$

Delivery = 31·26 × 2·4054 = 75·19 cubic feet per second.
= 2·129 cubic metres per second.

In order to dispose of arithmetical details, we may as well complete the calculation in the above case, so as to find what the thermal capacity of such an air stream is.

Reducing to standard conditions the delivery becomes—

1·864 cubic metres per second at 0° C. and 760 mm.

1 cubic metre of the mixture of air and water vapour measured under standard conditions would contain—

13·5 litres of water vapour.
986·5 litres of dry air.

The weight of these constituents would be 11·61 grammes for the water vapour, and 1,276 grammes for the air.

Thermal capacity of the water vapour with a specific heat of ·48 is 5·6. Similarly with specific heat of air of ·2375, its capacity is 303·0, making a total of 308·6. The water equivalent of 1 cubic metre of this air when measured under standard conditions is thus 308·6 grammes. If we suppose that 1 cubic metre of the air is heated through 1° C., then the electrical energy required is ·0215 Board of Trade units. The energy dissipated by the air stream is thus per degree of temperature rise and per cubic metre of delivery measured under standard conditions per second, 1,290 watts.

The actual stream was 1·864 cubic metres reduced to standard conditions, corresponding to 2,405 watts per degree rise in temperature. A convenient rise in temperature would be about 20° C.—corresponding to a dissipation of 48·1 kilowatts.

Arrangements at Dynamo.—Figs. 5, 6, and 7 give a general and sufficient idea of the arrangements adopted, for it is obvious that everything depends on the conditions obtaining in each particular case. The 300 k.w. A.C. generator investigated by the writer ran for about one-third of its diameter in a wheel pit of concrete, and the structure had to be arranged accordingly.

Assuming that the air flow can be properly measured, the chief

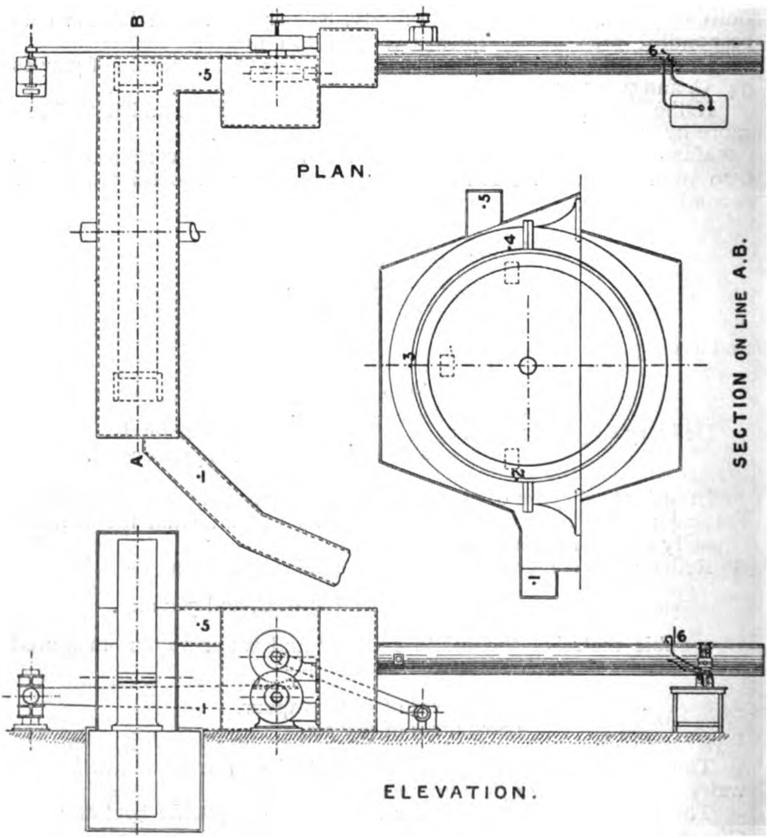


FIG. 5.

source of error lies in the possible leakage of heat into or out of the apparatus. So far as the upper part of the structure goes, it is quite easy to regulate the fan so that the mean temperature of the enclosure is only about the same as that of the engine-house, and this disposes at once of all danger of errors arising from direct leakage through the walls. The case is not so simple for the wheel pit, for though concrete is not a good conductor of heat, there was a good deal of it, and con-

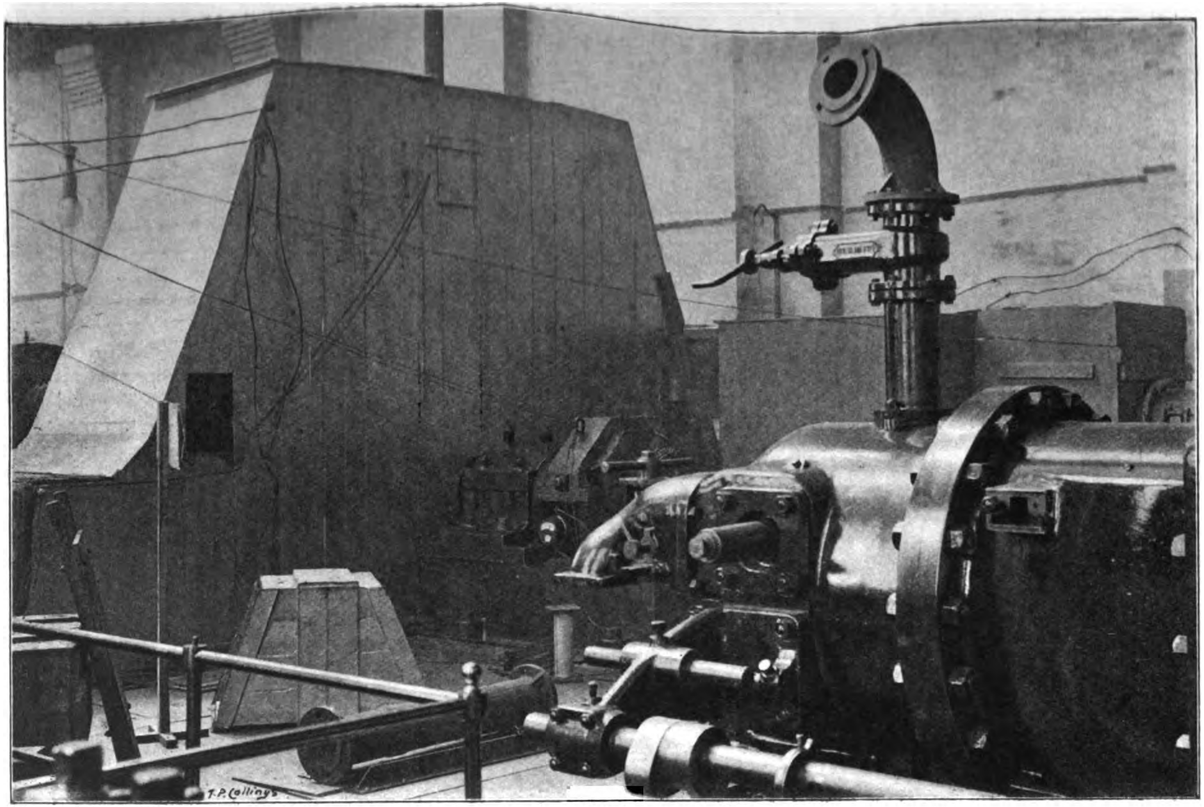


FIG. 6.

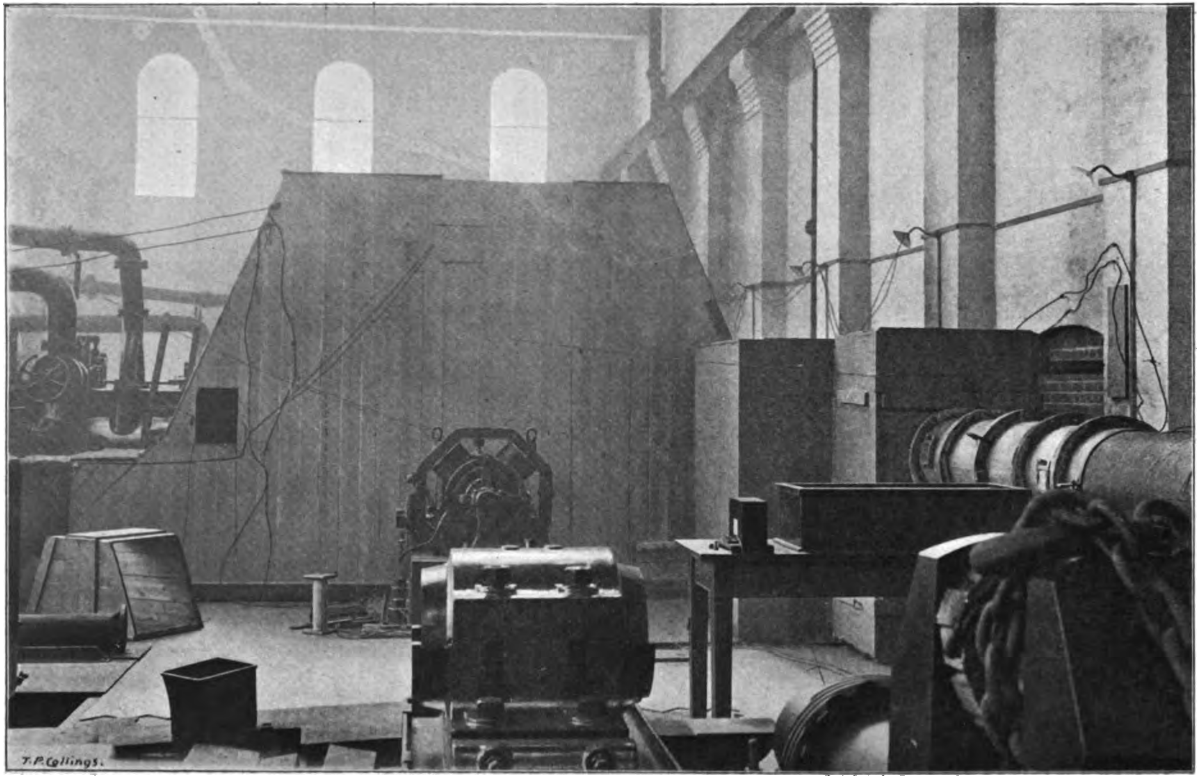


FIG. 7.

sequently elaborate precautions were taken. The pit was boarded round and felt ¾ in. thick fastened on over the boards. If the trial is prolonged till the temperature becomes steady throughout the system then the concrete may in this case be assumed to have very approximately the temperature of the engine-room, for the foundations were not filled in, but the concrete structures carrying the engine were freely exposed to the air. The boarding throughout was ½ in. T. and G. boards fastened to 4 in. studding. The casing was fitted as well as possible, and was then papered over with paper faced with bright—so-called—tinfoil, probably pewter foil. This not only acted as a preventive of air leakage, but gave a considerable degree of thermal insulation as well. Incidentally the paper was cheap and gave the apparatus a smooth and clean appearance. The entry air duct leading outside the building had an area of 4 square feet, and was protected from warming (rather unnecessarily), partly by felt and partly by the tinfoil paper. A window was provided at the junction of the air duct with the generator casing, and a standard thermometer was hung in a convenient position for observation through the window. There was a lamp which could be turned on when required, so that the observer might have every opportunity of observing as well as possible. The thermometer position is indicated by the figure 1 in the Plan, Fig. 5.

The air propeller was at the other side of the generator casing, and was placed in a large box; the air so drawn from the casing was propelled down the measuring pipe.

The opening into the fan box from the casing was of considerable size, though not really large enough, and the temperature was observed at several points in the opening by means of a standard thermometer—for instance, as indicated by the figure 5.

The arrangement described was decided upon before anything was erected, and was chosen on the assumption that there was sure to be a certain amount of air leakage into the casing from the engine-room. If this had taken place, the volume of air passed would still have been properly measured; the only error remaining over would have been in the false supposition that air entering from the engine-room had the same temperature as air entering from outside the building. In the event it turned out that it was quite easy to stop all appreciable leaks, so that for the future it will not be necessary to place the fan between the generator casing and measuring pipe unless it is more convenient to do so.

The object of bringing in air from outside the building was, of course, to start with air colder than that surrounding the generator casing.

By regulating the speed of the fan it was quite easy to adjust the air supply so that the average temperature inside the casing was the same as that of the engine-room; the air at entry was colder, and at egress warmer, but, owing to the stirring action of the generator, the walls of the casing were practically at the engine-room temperature. By this simple device so often used in calorimetry all errors due to unconsidered streams of heat were avoided.

Thermometry.—The thermometers employed were centigrade mer-

cury in glass thermometers, each degree being 9 mm. long and subdivided into tenths. These thermometers were Kew standards. They were compared together during the tests, and their positions were interchanged during the trials. No doubt special platinum thermometers recording the temperature difference of entry and exit would have been preferable if only in the saving in labour, but the writer's apparatus for this purpose happened to be absorbed in other experiments at the particular time of the trials. For a rise of 20° C. the temperature difference should be ascertained to about ·2°, and closer in proportion as it is less, so as to be accurate to about 1 per cent.

Fans.—Two fans by Heenan and Froude were employed to draw the air through the system. They were driven by motors, and took about five kilowatts between them. In many of the experiments one fan only was employed, and it would not have been necessary to use more than one in any case if more care had been taken to have all the openings as large as the air duct coming from outside the building, *i.e.*, 4 square feet cross sectional area.

Electrical Measurements.—The subject of power measurement in alternating-current circuits is one not altogether unfamiliar to those who were members of the Institution of Electrical Engineers in the early nineties. It might be supposed that nothing remains to be said on the subject, yet it is certainly not two years ago since the writer came across a statement by a competent authority to the effect that it was impossible to say how much energy was employed in producing a pound of carbide of calcium, for the reason that the manufacturers themselves did not know to within 20 per cent. what was being used. If this is really the case, it does not speak well for the scientific attainments of those engaged in the industry; but, even regarding it as a gross exaggeration, there is undoubtedly some foundation for the charge. The trials with which we have to deal were made by taking up the power in a large tank filled with water. In the greater number of the trials the current was led through iron strip measuring $\frac{3}{4}$ in. wide by $\frac{1}{25}$ in. thick, this strip being stretched round large nails driven into heavy boards nailed to the sides of the tank. Care was taken to wind the strip in zigzags about 2 inches apart, and the ends of the strips were brought up to near the surface of the water with which the tank was filled, so as to give some freedom of adjustment of resistance. Connection was made to heavy copper ribbon or bar which projected from the mains to the depth of about 2 feet under water. It was supposed that there might possibly be some doubt in the minds of the parties concerned as to the electrical measurement of the power, and consequently the tank was provided with about 250 feet of thin 2-in. leaden piping arranged so as to expose its full surface to the stream of hot water set up by the current in the strips, the latter being, of course, nearly at the bottom of the tank. Arrangements were made for sending a stream of water through this lead pipe and passing the stream over weighing buckets, an arrangement which had been previously used by the writer with complete success. It is obvious, in fact, that with proper thermometry such a power absorber is a huge calorimeter, and

would enable estimates of power to be obtained independent of any electrical instruments whatever. In the result the electrical measurements were found to be so satisfactory that recourse to calorimetry was not necessary.

The scheme adopted was the following: A suitable kilowatt balance by White, of Glasgow, was tested on a continuous-current circuit against multi-cellular voltmeters standardised by cells, and the currents directly measured by a potentiometer and manganin resistance tested by the standardising department of the Board of Trade. The constants supplied with the balance were thus verified to within a fraction of 1 per cent.—in fact, to within the range of possible experimental errors. The tests were carried out with about 80 kilowatts, and care was taken to use about the same electro-magnetic forces with the balance as were subsequently used during the trials. The balance was henceforward taken as correct. The resistances supplied for use in the pressure coils of the balance were tested against standards, and were found to require no correction for the present purpose. By varying the resistances in the pressure arm of the balance and altering the weight of the balance sliders it is possible to measure the same power under a variety of circumstances as regards the resistance of the pressure coil. From a number of experiments made some years ago on alternating currents of the frequency employed in these trials it had been found that changing the resistance of the pressure coil made no difference in the power measured, suitable weights being employed; it was clear, therefore, that the balance time constant was too small to affect its readings at the frequency used, and this agreed perfectly with the results of calculation, and with the makers' statement and certificate of test. The balance itself, therefore, may be regarded as trustworthy. As a check two independent methods were employed. An oscillograph was procured from the Cambridge Scientific Instrument Company, made according to Mr. Duddell's patents, and this was set up in a special observing-house erected outside the engine-house. The curves

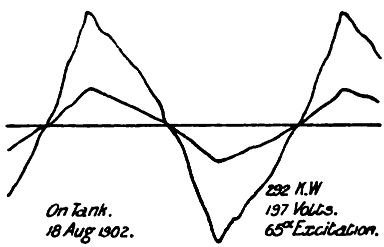


FIG. 8.

showed that both pressure and current curves passed through zero at the same instant to within 2 or 3 per cent., *i.e.*, as nearly as could be seen (Fig. 8). Photographs were taken of these curves on films placed over the tracing screen, and the records were examined at leisure. Both

current and pressure curves were fairly smooth and of the same form and still no relative displacement of the curves could be detected. A new instrument in the shape of a very sensitive hot-wire voltmeter was devised by the writer a year before the trials took place. With this instrument it was possible to make measurements of the voltage accurate to about 1 per cent. with less than half a volt as the total voltage in question. The instrument was calibrated by passing large unidirectional currents through the standard resistance of ·0002 ohm and simultaneously observing the P.D. by the new instrument, and by a comparison with cadmium cells. The alternating current it was desired to measure was then sent through the same resistance, made of many thin strips of manganin in parallel and exhibiting no measurable skin effect at the frequency employed. By making simultaneous observations on the Kelvin balance, a standardised multicellular voltmeter, and the writer's new instrument with its manganin resistance in the main balance circuit, it is clear that the question as to the accuracy of the balance can be referred to the fundamental units almost directly. The result was as before, to show that the balance had no error which was capable of detection by these appliances, *i.e.*, it was less than 1 per cent.

Heat Evolved by Generator.—After some preliminary trials, the makers of the generator suggested that it would be more satisfactory to them if some means were found for introducing a known quantity of heat. This could, of course, be measured in the manner adopted, and would give a means of testing the reliability of the method. It will be convenient to consider this test first, though it was not the first test made.

Ten lengths of thin iron strip, similar to the strip employed in taking up the load in the tank, were stretched in groups of five each above and below the shaft in the enclosure containing the generator: these strips were stretched in a zigzag, and when placed in parallel series of five strips each had a resistance of about 1 ohm. The total length of the strip was about 130 feet, the width $\frac{3}{4}$ inch, the thickness $\frac{1}{16}$ inch, and the total area of heating surface was therefore about 16 square feet. It was necessary, in order to reproduce the conditions of the test, to make sure that the strips were not too hot, and did not cover too circumscribed a space. If these precautions had been neglected, the air current could not have prevented the formation of hot areas on the casing, which would, of course, have led to an unusual loss of heat by radiation and air conduction. The engine was kept turning round at its usual speed throughout the trial.

Current was turned into the strip and the power was kept constant by external adjustment, the balance being used to measure the power employed, viz., 38 k.w. as it happened. The most convenient current to employ was an alternating current similar as to frequency, etc. (and generated by a similar machine) to the current generated during the tests. The details of this test are given in Table III., below. The heat supply of 38 k.w. was chosen as it was the amount which the generator appeared to liberate at full load.

TABLE III.

August 28, 1902.

ENGINE RUNNING UNLOADED AT 120 R.P.M.—FIELDS UNEXCITED.

Time. Start.	Inlet Temperature. F.	Outlet Temperature. C.	Power in k.w.	Temperature. Armature Core. C.	Temperature of Room in C. Front of Structure.	Temperature Back of Structure.	Anemometer Reading. Mm.	Hygrometer. Dry Bulb. F.	Hygrometer. Wet Bulb. F.
A.M. 11.45	70°	36·0	38·0	37·0	29·0	31·0	27·56		
P.M. 2.0	69·6	38·0	38·0		31·0	34·0	27·56	68·0	58·0
2.15	69·8	38·35	38·0	39·5	30·4	32·0	27·62		
2.30	70·5	38·40	38·0	39·7	30·0	31·2	27·72		
2.45	68·8	38·40	38·0	39·8		32·7	27·50		
3.0	68·9	38·30	38·0	39·8		32·0	27·64		
3.15	68·0	38·20	38·0	39·5		32·7	27·51		
3.30	68·4	38·30	38·0	39·7	30·3	32·1	27·54		
3.45	67·7	38·40	38·0	39·7	30·2	32·9	27·48		
4.0	68·6	38·45	38·0	39·7	30·0	32·2	27·56	68·5	59·0
4.15	69·6	38·8	38·0	39·7	30·0	31·2	27·70		

Barometer 748 mm. uncorrected. Average of inlet and outlet, 29·4° C.
Average inlet temperature, 20·28° C. } Difference, 18·23° C.
Average outlet temperature, 38·51° C. }
Average anemometer reading, 27·58. Anemometer zero, 21·92.
Average anemometer pressure difference, 5·66 mm. water.
Average temperature of armature—left-hand side in case, 39·7° C.
Average temperature of air in engine-room ... ... 31·15° C.
Average temperature of tinfoil covering. { Front—eight places, 33° C. Back—two places, 33 5 C.
Power as measured, 38·0 k.w.
Less loss in external leads, 0·2 k.w.
Actual power expended inside casing, 37·8 k.w.

Air Measurements.—Density of air at 748 mm. and 38·5° C. with humidity 52 per cent. at 68° F. ·00111 grammes per cubic centimetre.

Velocity at centre of pipe—

$$V = 1{\cdot}377 \sqrt{\frac{5{\cdot}66 \times 98{\cdot}12}{{\cdot}00111}}$$

= 974 centimetres per second.
= 31·95 feet per second.
= 1917 feet per minute.

Delivery of air = maximum velocity × area of pipe × 0·935.
= 1917 × 2·405 × ·935.
= 4310·5 cub. feet per minute.
= 122·1 cub. metres per minute.
= 105·3 cub. metres per minute at 0° and 760°.

Heat carried out by Air Stream.—Mass of air delivered per minute, 105·3 × 1·293 = 136·55 kilos.

Heat carried out, 136·55 × ·2375 × 18·231.
= 589·56 kilo calories per minute.
= 9·826 kilo calories per second.
= 40·865 kilowatts.

Heat supplied, 37·8 kilowatts.

Difference — excess, 3·065 kilowatts, uncorrected.

Corrections.

On August 20th a trial entirely similar to the above, but without any external source of heat being applied, and continued for about fifteen hours so as to allow of a steady state being attained, had given 2·066 kilowatts as the heating due to windage and conduction along the shaft. In this case, the temperature rise being only 1·554° C., air was drawn into the casing from the engine-room, the temperature of the casing being therefore about 0·8° C. above that of the room, as compared with about 2° C. in the trial under consideration. In both cases the loss by cooling may be neglected.

Adding the windage and shaft heating, we have finally—

Heat supplied	37·8 k.w. as electric power.
Heat due to windage and conduction	2·066 k.w.
Total heat supply	39·866 k.w.
Heat as measured	40·865 k.w.
Difference	0·999 k.w.

Difference (error) as percentage of true heat supply 2·51 per cent.

On August 26th another test was made under rather different conditions. The chief data are—

Anemometer pressure difference, 4·82 mm. water.
Inlet temperature, 17·99° C. Outlet, 36·8° C.
Temperature difference, 18·77° C.
Kilowatts supplied, 37·8.
Air supplied, 98·01 cubic metres per second at 0° and 760°.
Heat measured, 39·16 kilowatts—gross.
Heat measured, less windage, etc., 2·066. 37·094 kilowatts.
Difference —·706 k.w.: *i.e.*, there is a loss of that amount.
Difference as percentage of true heat supply, —1·77 per cent.

Taking the two tests together, the average error is—

$$\frac{2·51 - 1·77}{2}$$
$$= + ·37 \text{ per cent.}$$

Before leaving these tests a word may be added as to windage and heating by conduction along the shaft. The shaft may be taken roughly at fourteen inches diameter, and three feet may be taken as the distance between the bearing and the hub of the flywheel. If we take the temperature of the bearing as 80° C. and that of the flywheel hub as 30° C., and regard them as a perfect source and perfect sink of heat respectively, it is easy to calculate an upper limit to the amount of heat carried in by conduction. For this purpose we may take the conductivity of the shaft at 0·2, the highest published value, and assume that the shaft loses no heat from its cylindrical surface. The result of the calculation is a maximum heat supply of 0·36 k.w., while probably one-fifth of this amount would be nearer the mark, seeing that the shaft is revolving 150 times per minute and is exposed to the air. 0·07 k.w. will be taken as a possible value. The windage and conduction between them accounts for 2·066 k.w., so we may say that the windage alone is 2 k.w., and arbitrarily charge half of this to the engine and half to the generator.

TESTS OF GENERATOR EFFICIENCY.

In all of the following tests the method employed was the same as that fully described in the last section, and consequently the details of each test need not be given. The generator was run in all cases till the temperature became steady throughout the system. The fans were carefully kept at as nearly a constant speed as possible by keeping the voltage on the motors constant. Observations were made of the temperature of the air at two or three places on each side of the casing. The temperature of the casing itself was measured by holding a thermometer against it, the bulb of the thermometer being held against the casing by means of a large cork with a V-shaped depression cut across one face. This method was found to give accurate results by the following test: A certain furnace casing made of iron having been observed to be nearly cold at one side while it was hot at a point some three feet away, a piece of pure prismatic sulphur was employed as a pencil to draw a line from the hot to the cold area. The point of fusion of the sulphur was seen with exceeding sharpness. The thermometer was then held against the furnace casing by a cork cut as described, and was found to give (within a very small fraction of 1° C.) the correct melting point of prismatic sulphur.

During the observations for engine efficiency three observers read the temperatures, Kelvin Balance and Anemometer—a complete set of readings taking about ten minutes. As soon as one set was finished another was begun, and at the end of about an hour all the data were brought on to a single sheet and averaged. The generator output was kept as nearly as possible constant by varying slightly the resistance in the shunt field of the exciter and adjusting the gas valve of the engine. A summary of results appears in Table IV. including the tests already described.

TABLE IV.

Date. 1902.	K.W.	Magnetising Current.	T. C.° Inlet.	T. C.° Outlet.	(Inlet + Outlet)/2.	Mean Temp. of Casing Back and Front.	Heat Supply Measured. K.W.
13 Aug.	301·42	65·9	16·186	32·19	24·2	24·25	38·01
19 "	0	51·83	19·44	30·35	24·9	28·2	25·04
20 "	0	66·2	15·415	26·83	21·12	24·75	27·20
20 "	0	0	24·42	25·97	25·20	24·4	2·066
21 "	249·2	57·5	20·17	33·54	26·87	30·8	34·16
26 "	37·8		17·99	36·80	27·4	29·4	39·27
28 "	37·8		20·28	38·51	29·39	31·15	40·865
29 "	262·4	61·2	20·95	36·35	28·65	33·10	34·07

From the above table are omitted several other tests at full load, all of which gave very nearly the same result but were not actually considered, owing to some of the parties being unrepresented, or for some similar reason. Taking the test on August 13th, which was at the highest load, we can now deduce the efficiency of the dynamo. Allowing 1 k.w. loss for windage chargeable to the engine, the generator may be said to waste 37·01 k.w., together with whatever *loss* of power there may be in the exciter, this machine, though mounted on the end of the main shaft, not being included in the casing. The *output* of the exciter, however, appears as loss in the heating of the magnets, and is duly included. Neglecting the loss of power or heat generated in the exciter itself for a moment, we may say that the generator efficiency is

$$E = \frac{301{\cdot}42}{301{\cdot}42 + 37{\cdot}01}$$
$$= 89{\cdot}05\%.$$

The exciter current was 65·9 and the external voltage 33·7, say. Assuming that the exciter efficiency is 83%—it was lightly loaded and of a well-tested type—we may say that its loss is

$$\frac{17 \times 2{\cdot}221}{83} = {\cdot}455 \text{ k.w.}$$

Making this correction, the overall efficiency of generator and exciter taken as a single unit is

$$E^{1} = 88{\cdot}93.$$

There is in this case no addition to be made for belting, as the exciter was mounted on the end of the main shaft. The friction in the outer and inner bearing is perhaps unjustly charged to the engine, on the ground that the flywheel carrying the magnets could not work without two bearings, as stated above. On the other hand, the engine is handi-

capped by having the extra weight of the magnets to contend with, *i.e.*, the mass per unit moment of inertia of the flywheel is greater than it would have been had the wheel been designed for a given moment of inertia without the limitations imposed by the alternator ring.

The question arises as to how the losses observed are made up. This is rather a question for the dynamo makers, and it will be fairer to allow those concerned to make whatever contribution they please in regard to the matter. Attention may, however, be directed to one or two points. In the first place, the copper magnetising loss is small, being 2·221 k.w. in the test considered. In the second test in the table, viz., that on August 19th, the alternator being run on open circuit, the magnetising current was adjusted so as to give the same internal alternating voltage as had been used during the full-load trial: the magnetising current was 51·83 amperes, corresponding to a loss of about

$$\frac{2{\cdot}221 \times (51{\cdot}83)^2}{(65{\cdot}9)^2} = 1{\cdot}37 \text{ k.w.}$$

At the same time the total loss in the casing was 25·04 k.w., so that subtracting windage loss, viz., 2·066 k.w. as well as the Joulean waste in the magnet windings, we have $25{\cdot}04 - (2{\cdot}066 + 1{\cdot}37) = 21{\cdot}60$ as the iron losses pure and simple, the iron being brought up to the same induction as during the full-load trial. Now, if we treat the loss at full load in the same way, we find the iron loss + the copper loss in main conductors $= 38{\cdot}01 - (2{\cdot}066 + 2{\cdot}221) = 33{\cdot}723$.

An estimate can easily be made of the copper loss from the measured resistance of the alternator, making some allowance for "skin effect," which, however, is not important, the conductors being of rectangular section and four times as wide as they are thick. Frequency about 40 $\sim$. The copper loss at full load is therefore about 3·07 k.w. Subtracting this, we have as the iron losses at full load $33{\cdot}723 - 3{\cdot}07 = 30{\cdot}653$,
and at no load, 21·60.

It occurred to the writer that this difference might perhaps be accounted for by the iron losses in the cores of the *magnets* at full load. The machine had been purposely designed for a constant k.w. output with varying external resistance and large overload capacity—necessitating a high armature reaction, and it was evident that this must mean considerable fluctuation in the inductance of the cores and a corresponding fluctuation of the magnetising current. Test 3 will bring out the consequence of this reactiveness, for it shows that with the same magnetising current as that used at full load the no-load losses rise to 27·2 k.w., as against 25·04 k.w. in test 2, where the machine was excited merely so as to give the full-load voltage.

ENGINE EFFICIENCY.

As soon as the dynamo efficiency is known it becomes the best possible "brake," and we may proceed to examine the behaviour of the engine.

It would be outside the scope of this paper to consider the result of such tests in detail, but it may be mentioned that the engine in question

was most carefully indicated over the period of the tests already mentioned, and that the following figures were obtained, the engine being a two-cylinder tandem gas engine:—

Gross total, I.H.P.	517·05
Absorbed in pumping and friction at no load ...	70·00 (indicated).
Mechanical efficiency resulting	86·5%
Mean power	301·42 k.w.
Dynamo efficiency overall	88·93
Resulting k.w. delivered by engine	338·9
Indicated k.w.	385·75
Resulting mechanical efficiency	87·86

This is possibly the most reliable result hitherto obtained for a gas engine of this size.

It is the writer's hope that other engineers will, as opportunity or necessity arises, adopt the thermal method of testing such generators as cannot be tested except by the very indirect method of making a brake test of the engine. If this be done it seems likely to lead to increased care being taken by makers of electric generators both in the design of their machines and in the "guarantees" as to the efficiency usually based hitherto on purely *à priori* calculation.

In initiating a system of testing it is right and proper to consider as far as possible every source of error, and this necessarily leads to the discussion of much detail; but it must not be inferred that the test is difficult to make. In the first place, it shares with the well-known Hopkinson test the advantage that the power lost is the direct subject of measurement, and a considerable error may be made in this estimation without proportionately affecting the result so long as machines of high efficiency are in question. For instance, suppose that a 100-k.w. machine under full load is being investigated: let the measured loss attributable to the machines be 10 k.w.—the resulting efficiency is

$$\frac{100}{110} = 90{\cdot}91\,\%.$$

Suppose that an error in the loss amounting to 10% of the apparent loss has been made, and that instead of 10 k.w. it is really only 9: the efficiency of the generator would then be really

$$\frac{100}{109} = 91{\cdot}74,$$

and the error of the estimate would be $91{\cdot}74 - 90{\cdot}91 = {\cdot}83$—*i.e.*, less than 1% in the percentage efficiency figure.

The writer's thanks are due to his assistant, Mr. R. H. Bradbury, who undertook most of the anemometry and reduction of observations; and to the makers' representative, Mr. A. C. Coubrough, who began with a wholesome distrust of the whole system of testing, and after criticising it at every turn most carefully, and carrying it through himself on many occasions for the sake of the information it afforded on points

of interest to designers of alternators, ended by attaining confidence in the results obtained.

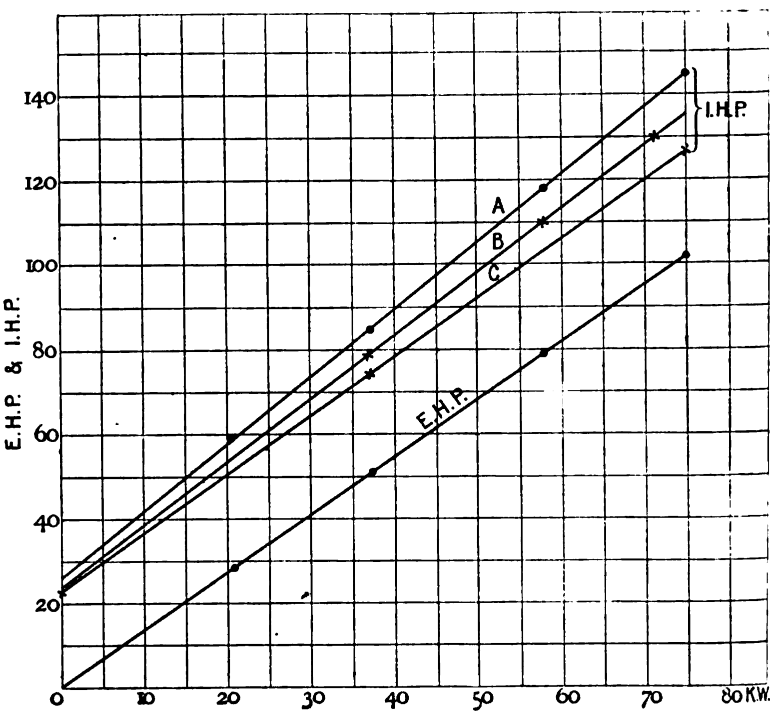
The total works cost for labour and material for setting up the testing apparatus was £19 9s., of which the greater part was for the wood used to make the casing, and which was afterwards used up for the most part, but the test is not credited with its second-hand value.

Mr. W. B. Esson: I think Professor Threlfall's paper is extremely interesting. So far as I know, the method of testing is quite novel, and I am glad to see that it gives the results which might have been expected. I cannot help thinking that it is a method which requires a great deal of experience. No doubt in the hands of an expert like Professor Threlfall the results might be confidently relied upon; but I must say quite frankly that, until I had had a good deal of experience, I should regard with some suspicion the results which I might obtain. So far as I can judge by reading the paper there are many sources of error. It is rather an indirect way of testing, and it is difficult to carry out unless one is practised in calorimeter methods. Some time ago Mr. Mordey, I remember, tested the efficiency of a transformer by a calorimeter method (*Journal Inst. Electrical Engineers*, vol. 20, p. 203) and he discovered, much to the surprise of everybody, that whereas the iron loss at full load was considerable, at no load it almost disappeared. No doubt Mr. Mordey has seen the error of his ways since then, but from the results he obtained I cannot help thinking that this method of testing, tests the operator just as much as it tests the apparatus from which he is endeavouring to obtain results. In the case of the transformer, certainly it was the operator and not the hysteresis loss that the method found wanting. Mr. Esson.

Coming to the matter, to which I made some reference in my recent paper, *i.e.*, the loss at no load, and the loss at full load, I see that Professor Threlfall found the iron loss at full load to be something like 10 per cent. of the output of the generator, while at no load it was found to be approximately 7 per cent. of the output. The difference is 3 per cent., it is a loss unaccounted for, which increases from no load to full load by about 50 per cent., and it is difficult to locate. Something like eight years ago, a case came before my notice in which an alternator tested on a Willans engine showed a very large "load loss" between no load and full load. We could, of course, ascertain the power taken to drive the machine, excited but unloaded, and knowing the friction law of the Willans engine we ought to have been able, by adding the armature copper loss at full load and the output, to get quite easily the indicated horse-power at full load. The I.H.P. was considerably more, however, than such a calculation would show, there having to be added for full load, instead of merely the copper loss, an amount equal to no less than 7·6 times this. The author demonstrates in his paper, that in the particular generator he tested the iron loss appeared to increase by 50 per cent. at full load, or in other words the loss added for full load is not only the armature copper loss but four times this, which is no unusual result. Another machine was built, similar to the

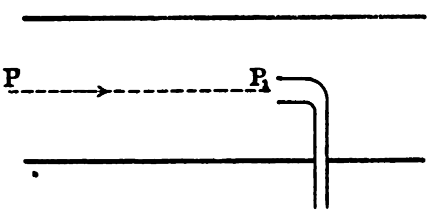
Mr. Esson. one I have referred to as showing such discouraging results, but in the second machine the poles were laminated. Then this "load-loss" almost disappeared, and we got very little increase in iron loss, from no load to full load. This would tend to show, as the author points out, that the loss is in the poles of the generator, and not in the core. I should, therefore, like to ask whether the poles in the particular machine tested were solid poles, or thoroughly laminated poles, or partially laminated poles. [Professor THRELFALL: You are quite correct: the loss was in the poles, and they were only partially laminated.] The loss must be due then, as was the cause in the machine I have mentioned, to eddy currents in the poles, and it would seem to show that merely laminating the tips of the poles, that is partial lamination is not sufficient if you want to get a very high efficiency, and do not want to get a "load-loss." Really the poles should be laminated right through. I would point out in conclusion that Mr. Blathy, some time after my experiments had been carried out, found the same results in testing continuous-current machines. He found there was "load-loss" increasing with the current, which he deemed also to be due in some way to eddy currents in the pole pieces.

(*Added December* 9, 1903.) This matter of the "load-loss" is so important that I venture to hand in a diagram showing the results I obtained on the machines above referred to. On the base line is



marked off the output in k.w. given by the machine, and ordinates give the E.H.P. and I.H.P. The three lines A B and C show the latter, with the machine running under three separate conditions. A gives the I.H.P. when the machine was originally tested with solid poles. B gives the I.H.P. when the poles had been grooved on the face to a depth of $1\frac{1}{4}$ in. with grooves $\frac{1}{4}$ in. wide by $\frac{5}{8}$ in. pitch. It will be seen that the total loss at full load in the first case is about 80 per cent. more than unloaded, which is not at all a good result. In the second case the increase is about 50 per cent., and this is still not a good result, though in the machine tested by Professor Threlfall it is not lower. When we come to line C, however, which gives the I.H.P. with the pole tips laminated to a depth of about 2 inches, this remains very nearly parallel to the E.H.P.-line, showing that the no-load loss increases by only about 10 per cent., or about what the copper loss in the armature would account for. It may be mentioned that the armatures were stationary, and that there was no discontinuity of surface in the interior to account for the losses made apparent in the first two tests. Mr. Esson.

Dr. R. T. Glazebrook: I should like to say one or two words about the Pitot tube method of measurement, especially as we have been working at the National Physical Laboratory for the past year and a half on the measurement of air pressures, and have been using with very great success this same method of measurement to which the author has referred. If I may use the board for one moment, I think I can explain very simply all that I desire to say. The author has referred to Lord Rayleigh's work on the subject, and to his paper about the measurement of air pressure, and he said that Lord Rayleigh had arrived at a certain co-efficient instead of $\frac{1}{2}$. That, of course, is quite true; but Lord Rayleigh went on to point out how the co-efficient $\frac{1}{2}$ could be obtained; and the method he suggested for obtaining the co-efficient $\frac{1}{2}$ is the method adopted in the Pitot tube, so that the author's result that the co-efficient is very close to $\frac{1}{2}$ really bears out fully and completely the theoretical work of Lord Rayleigh; and, as a matter of fact, Dr. Stanton, at the National Physical Laboratory, has arrived at very nearly the same co-efficient—not exactly, because there is a slight difference in the arrangement of apparatus. Dr. Glazebrook.



Let us for a moment consider a tube with a stream of air, and fix our attention on a single stream line along the centre of the tube. Consider two points, P and P_1, in the stream. Let p, v be the pressure and velocity at P, p_1, v_1 at P_1, and let ρ be the density. The energy per unit volume at P is $p + \frac{1}{2}\rho v^2$; that at P_1 is $p_1 + \frac{1}{2}\rho v_1^2$, and it follows that, if there are no forces acting on the fluid, $p + \frac{1}{2}\rho v^2 = p_1 + \frac{1}{2}\rho v_1^2$. This condition is practically true in the stream of air.

Dr. Glazebrook.

Suppose now it is possible by some means to stop the motion at P_1 so that v_1 is zero.

Then we have $p_1 - p = \frac{1}{2}\rho v^2$, and this quantity $p_1 - p$ is exactly the quantity that has been measured by Prof. Threlfall in his Pitot tube experiments. The facing tube, as he calls it, measures p_1, and the gauge tube at the side measures p, and this formula is true provided the velocity of the moving stream of air is reduced to nothing at P_1. Lord Rayleigh points out that if you merely put a flat obstacle at P_1 you do not reduce the velocity to nothing: the stream of air passes by the sides, and the velocity is not reduced to zero; hence you do not get this formula holding exactly, but one with another co-efficient, which is not exactly $\frac{1}{2}$. But if you place a small cup-shaped obstacle at P_1, with very narrow edges pointing towards the flow of the fluid, then the fluid is stopped from flowing round the edges of the cup, and the velocity of the air flowing into the cup is reduced to zero at the bottom, and therefore the theoretical equation holds. We have found, as I said, that that theoretical equation practically holds. The co-efficient is not exactly $\frac{1}{2}$, and it differs from $\frac{1}{2}$ not quite to the same extent that Prof. Threlfall's co-efficient does; but that, I think, is due to the considerable difference in form of the Pitot tubes used, and also to the fact that our second gauge tube—the tube that appears in the side of the main tube in Prof. Threlfall's diagram—is placed in the main stream line which we are measuring, while the whole arrangement of the Pitot tube is extremely small compared with the tube that the author has been using. As to the column of air, I think we have been using one 2 ft. in diameter, rather bigger than the one he was actually using. The important result, however, remains, as he points out in his paper, that it has been shown by these experiments, which are about to be described shortly elsewhere, that the Pitot tube is a very accurate instrument for measuring streams of air, and therefore this kind of method of air calorimetry becomes much more easily feasible than it was before that result had been arrived at. With regard to the calorimetric result, there is just one question I should like to ask. I gather that the stream of air that entered and was drawn out was 21 in. in diameter. I should have supposed that there was a considerable difference in temperature between different parts of that stream, and I am not quite sure if that point has been looked into. Again, the efficiency of his engine was measured under a considerable stream of cool air coming in, so that I take it—I do not know if I am right on the point—that the temperature of the whole machine was distinctly lower than it would be in practice, and that therefore his machine was not working under exactly the same conditions that it would be working under when running with its usual load. I should have thought that the effect of the fanning of the air on the machine, maintaining it generally at a lower temperature than is usually the case, might have been a considerable factor in the result.

Mr. Mordey.

Mr. W. M. MORDEY: I am sure that anybody who has had to do with measuring the efficiency of alternate-current machines will welcome any proposed new method, especially one like the present, that is equally suitable to direct or alternate currents, and to either generators, motors, or rotary converters. Professor Threlfall's method

Mr. Mordey.

is very interesting, and to me especially so on account of his remarks on the measurement of air, as I am just now considering, with Mr. Dawbarn, a question which may become a very important one before long—the measurement of the quantity of gas passing to large gas engines. From the author's investigations on the Pitot tube and from Dr. Glazebrook's remarks, it seems that greater confidence can be placed in the Pitot method than one might at first sight expect. Will the author say whether the curve of pressure at different points in the diameter given in Fig. 4 is taken on a vertical or horizontal line? There is a good deal of difference between the values on the two sides of the middle line. I would also ask what precautions have to be taken as to the inside surface of pipes to which this method may be applied, and to what extent will the values obtained at one time be influenced by any changes which may take place in the surface friction due to deposits of dirt or dust in the pipe? From the figure there seem to be quite different pressures near the two sides. To what is this due?

Perhaps the greatest usefulness of the author's method may prove to be in works where it will be easier to have an apparatus of this sort than in a generating station where tests have only to be made very occasionally.

At a first reading of this paper the objection presents itself that apparently a good deal of time will be necessary to get reliable results. One of the causes for the very rapid progress that has been made in electrical machinery has been the ease and quickness with which measurements have been made. This has made it possible to find out at once the effect of changes in design, and to compare different apparatus without loss of time. I hope I am wrong in supposing the author's method does not lend itself to quick observations. Perhaps he will tell us how long it would take to ascertain correctly the loss at no load, and the efficiency of a large machine at one-third, two-thirds, and full load. A large machine requires many hours running to attain its full steady temperature at any given load, and if I do not misunderstand the present method, accuracy can only be expected after a steady temperature has been attained, and during that time the current of air and the temperature of the air should be kept constant, as otherwise a steady temperature could not be attained. Sufficient time must be allowed for the absorption of heat by the machine itself, and this may be a very serious quantity. For example, a 300-k.w. machine weighing 15 tons would require to raise it to an average temperature of 50° F. above the air, no less than 80 H.P. hours. If we assume its efficiency to be 0·9, this would mean that even if no heat were lost by the machine (quite an impossible condition), it would require nearly two hours to attain that average temperature. If the efficiency were higher, the time would of course be longer. Any changes in the load or alterations in the losses would proportionately affect the out-going current of air only after a long time had elapsed. For these reasons it seems that however accurate the method may be under suitable conditions, it is not one that will be generally useful, although it may be very valuable in certain cases.

Mr. Mordey. I see the author, at page 50, gives the I.H.P. of the engine. Is that quantity capable of being ascertained with accuracy of the same order as the other important figures, particularly is that possible with small loads?

Mr. Esson has referred to an interesting point—the increase of losses when a machine is loaded—and has mentioned a paper by Mr. Blathy. When Mr. Blathy made the rather startling announcement in his paper, I tested some alternators by a modification of Hopkinson's method, and found no such increase as Mr. Blathy had discovered. I also found that the tests given in Hopkinson's classical paper showed no such increase—this was on smooth-cored armatures.*

Mr. Esson seems to doubt the possibility of decrease of losses with load, but as a matter of fact losses may either increase or decrease due to load, or may remain unchanged. A decreasing loss may occur in any machine where the eddy current loss at no load is large. Instances of such decreasing losses will be familiar to students of early dynamos; for example, the Gordon machines at Paddington took less power to drive them when fully loaded than when they had no external load at all, and it was a common thing with the Wilde machines for the power to remain practically constant through large variations of load. Similar but small changes may take place in transformers. We know more about the mechanism of these losses now, and how to prevent them, but they still often occur with widely spaced teeth and with unlaminated fields, and are due to changes in distribution of the magnetism, to tufting of the lines, to increase of the eddies, and of the hysteresis not only in the teeth, but also in the poles and in other parts of the machines. Tests such as Professor Threlfall's often reveal unsuspected losses. The machine he used was certainly well adapted to illustrate the practical importance of actually determining the losses, as its efficiency was unusually low. One can only hope, for the credit of this country, that it was made abroad.

Dr. Chree. Dr. CHARLES CHREE, F.R.S. (*communicated*): When a liquid is in "steady" motion and work is not being done by external forces, the relation between pressure p, density ρ, and velocity v along a stream line is $\int \frac{dp}{\rho} + \frac{1}{2} v^2 = \text{constant}$. If the pressure alone vary, then if suffixes 1 and 2 refer to two points along the stream line,

$$p_1 + \tfrac{1}{2}\rho v_1^2 = p_2 + \tfrac{1}{2}\rho v_2^2,$$

and if $v_2 = 0$ then $p_2 - p_1 = \frac{1}{2}\rho v_1^2$.

Mr. Threlfall's statement on page 30 would seem equivalent to this result, supposing the air inside the Pitot tube is really "quiescent." The formula which the author actually employs (page 33) implies a reduction of about $2\frac{1}{2}$ per cent. in the velocity below the theoretical value. It would be interesting to know what this difference represents, and whether it varies with the Pitot tube or with the conditions of the experiment. Possibly the obstruction due to the presence of the Pitot tube itself may not be wholly negligible, especially when the tube is near the wall of the pipe, or the pipe is narrow. When the

* *Electrician*, vol. 37, pp. 375 and 446, July, 1896.

velocity does not remain constant, the record from a Pitot tube tends, as Rateau has pointed out, to exaggerate the mean velocity, and possibly this may have had something to do with the reduction factor found necessary. Dr. Chree.

The author's reference on page 33 to a result, which he attributes to Darcy, seems hardly clear. As the velocity in a pipe when there is symmetry alters in a *continuous* way from the centre to the wall, the mean value must be found over the perimeter of *some* circle. Thus the mere fact that such a circle exists in every individual symmetrical case is evident *à priori*. The fact that the radius of this circle bears to that of the tube a ratio which is independent of the size of the tube, or the velocity of the air, is, if true, obviously important. Mr. Threlfall's own results, however, in Table I. (page 37), make the ratio in question vary from ·863 to ·721, and the lowest of these values is higher than the value ·689 which he ascribes to Darcy. This point seems to want some further explanation.

When the velocity along a diameter of the pipe does not possess equal values at points equidistant from the centre, but on opposite sides of it, the locus of the points where the velocity possesses its mean value is probably not a circle at all, and certainly not a circle concentric with the tube. If the want of symmetry in the velocity distribution is considerable, the method of splitting the section into circular annuli, exemplified by Mr. Threlfall, on page 38, may not be altogether satisfactory.

In dealing with the barometric reading on page 39, if "correction neglected" means that the barometer reading was not reduced to 0° C., this seems hardly in keeping with the number of figures retained. When dry and wet bulb thermometers are employed, and ordinary English hygrometric tables are used, it is simpler to get the vapour pressure, in inches, straight from the "dew point," and convert to millimetres from a table. The use of "relative humidity" is necessary only when one uses a hair hygrometer.

As regards the thermometry, if accuracy to 0·2° on a range of 20° C. is necessary, it is just as well, in view of possible combination of errors, to make sure of the relation between the hydrogen scale and that of the glass-mercury thermometers employed, and if the latter are not used in the position in which they were standardised, the difference in the "internal pressure" may merit consideration.

Discussion on Prof. Threlfall's Paper at Meeting of Birmingham Local Section,* December 16, 1903, Dr. W. E. Sumpner in the Chair.

Mr. Henry Lea said it was a matter of great satisfaction that after about two years' experiment Professor Threlfall had demonstrated the reliability and the accuracy of the Pitot tube. The Professor mentioned the difficulty of getting accurate measurements unless the Pitot tube was Mr. Lea.

* The Discussion of the Paper by the Birmingham Local Section is, for the convenience of the reader, interpolated in the Report of the Ordinary General Meeting in London. Prof. Threlfall's reply will be found on p. 61.

Mr. Lea. put a good way off the entrance of the main air duct. [Professor THRELFALL: A 22 in. pipe, if I remember right, requires a distance of about 20 ft.]. In the case of water there were sometimes irregularities in the internal core of the pipe which produced a revolving vortex of water, and it issued in a wide and diffuse stream. By putting in a diaphragm, however, the main rotation of the water was destroyed. He should like to know if Professor Threlfall in his experiments had tried the effect of putting in a vertical division, or even two crossing each other at right angles, in order to destroy any rotating effect in the main air-duct due to the revolution of either the fan or the alternator. It was very satisfactory to note that Professor Threlfall found there was no variation in the velocity distribution, if the velocity of the air stream changed as a whole.

Professor Burstall. Professor F. W. BURSTALL said the paper was a very remarkable illustration of what could be done by a very simple apparatus in the hands of a highly skilled individual. Though previous investigators had discovered the distribution of flow in a similar form to that which Professor Threlfall recorded, and were also aware that part of the momentum was destroyed, yet they did not succeed in getting any results worth having because they were not able to prove how much momentum was destroyed. He thought engineers were particularly indebted to Professor Threlfall's skill as a physicist. If he had not been an accomplished physicist he could never have done this work. At the same time that was perhaps a weakness in a sense, as the apparatus required an expert to handle it. He was afraid that, in the hands of the majority of works engineers, with the best intentions in the world the tests would not give results anywhere near the 3 per cent. mentioned by Professor Threlfall. What the average electrical engineer liked, and he quite sympathised with him, was a direct reading instrument with a pointer travelling round the dial to show the output of his machines. Of course the accuracy of Professor Threlfall's system depended upon two things. The thermometry could be done differentially by resistance thermometers with an accuracy surpassing that of any of the other apparatus. But there was another method of measuring the volume of the air passing,—rather more complex, but still effective. He (Professor Burstall) had recently had occasion to devise an arrangement for measuring the air drawn into a gas-engine of about 110 B.H.P. That, as near as he could tell, meant about 30,000 cubic ft. of air per hour, a comparatively small quantity as compared with the amounts measured by Professor Threlfall. He rejected the Pitot tube as being too rough, but on the other hand a meter of the full capacity was impracticable. A large meter was, however, employed; and he had arranged in the first place to use it for calibrating three anemometers placed *in series* with it. The calibration could be carried out at different rates of flow up to 8,000 c. ft. per hour with an accuracy approaching one per cent. In order then to measure a current of 28,000 c. ft., the three anemometers were put *in parallel*, and suitable arrangements made to ensure that the stream lines took exactly the same directions when parallel as when in series. One had then only to take three readings of the anemometers to get the flow. The anemometer method might be found even pre-

Professor Burstall.

ferable to that of the Pitot tube. It came to him as a great surprise to be told that the distribution of velocity was not affected by the velocity as a whole. With a changing velocity, say from 3 ft. a second up to 60 or 80 ft., would the same law hold throughout? He should not be very much surprised, knowing something about air work, to find that that law would only hold over a comparatively narrow range. The whole subject was one of extreme difficulty. In considering Professor Threlfall's results they must remember that this particular engine was of the scavenger type. He would like to know if Professor Threlfall found the same results in the non-scavenger type. The cylinder was much hotter in case of full load on the scavenger engine when the displacer piston was about to pump the air in, and the fluid losses were reduced thereby. That was the reason probably for a better result at full load than was obtained by subtracting the light load losses. He regarded the paper as so important that he thought it was highly probable he should use a modification of Professor Threlfall's method to determine the efficiencies of the whole of their plants at the new University buildings at Bournbrook.

Mr. Griffiths.

Mr. H. GRIFFITHS asked for elucidation of the figures relating to the tests made with a two-cylinder tandem gas engine. The kilowatts delivered by the engine were given as 338·9. Taking the total H.P. 517 and subtracting the 70·00 H.P. absorbed in friction and pumping, one obtained 447 B.H.P., which in kilowatts would be 333·49, not 338·9. The latter figure was obtained by taking the 88·93 efficiency and multiplying the mean power by it.

Professor Threlfal.

Professor THRELFALL said that he did not want to insist too much on his answer, because the question needed consideration. The first figure, 338·9, was based simply and entirely on the mechanical efficiency figure of 86·5 per cent., which was obtained by the engine indicator at no load and full load. The table should have been divided into two parts for greater clearness. What was meant was this: By indicating the engine at no load and at full load, and assuming that the mechanical efficiency is constant, a value can be assigned to the mechanical efficiency. The electrical output being measured and the engine indicated, the dynamo efficiency can be calculated by using the figure for the mechanical efficiency of the engine. But if we measure the dynamo efficiency, then in like manner we can deduce the mechanical efficiency of the engine. The table is intended to give in the first four lines the result of measuring the engine efficiency and deducing that of the dynamo; and in the last four lines the result of measuring the dynamo efficiency and deducing that of the engine.

Mr. Forster.

Mr. A. LINDSAY FORSTER asked whether Professor Threlfall saw any prospect of arranging some standard form of Pitot tube, which might result in its becoming a commercial instrument of accuracy. At present it seemed to be regarded by many of the speakers with a good deal of scepticism, due largely to the fact that it would not always be possible to place it in the hands of one possessing the great experience of Professor Threlfall. As to the question of friction losses, the gas engine seemed to come between, say, a Belliss and a Willans steam engine. It appeared to him that the gas engine would more nearly approach the

Mr. Forster. condition of the constant thrust type (Willans) owing to the pressure caused by the compression being present even on no load. Did Professor Threlfall consider that this had any influence on the question he raised?

Dr. Morris. Dr. D. K. MORRIS referred to the method of testing large gas-engines which had been shown to the members of the Institution on the occasion of their visit to Germany at the works of Messrs. Körting Bros. The load was obtained by coupling direct to the gas-engine shaft a field-magnet system which revolved in a water-cooled, cast-iron shell in which eddy currents were induced. The load was then regulated by the field-magnet excitation, and measured by the rise of temperature of the circulating water. Reverting to Professor Threlfall's method, he called attention to the considerable time for which it was necessary to continue the test in order to obtain a steady temperature, owing to the large thermal capacity of the machine under test. This would, no doubt, offer no serious difficulty in the case of a test such as Professor Threlfall described, but he would like to suggest that perhaps the thermal capacity of the machine might actually be made use of in the case of completely enclosed motors. Could not these be conveniently tested by measuring the rise of temperature of the winding and other parts of the motor, and directing attention particularly to the rate of rise at the time when the normal full-load temperature condition had been attained? This rate of rise could be reproduced artificially by supplying heat electrically inside the motor at suitable points, and the amount of the losses thus measured by electrical instruments. He asked whether Professor Threlfall considered that the generator in his test was under normal full-load conditions as regards temperature?

Mr. Bate. Mr. A. H. BATE said there would naturally be some vibration in a building when testing a large alternator. Were means taken to prevent the communication of that vibration to the water in the gauge tubes?

Mr. Taylor. Mr. A. M. TAYLOR said that there was, at present, a great difficulty in making a test of an alternator connected with an engine *in situ*, and undoubtedly Professor Threlfall supplied them with a test which gave all the normal conditions of running. He was not at all sure, however, whether the average engineer would not feel more certain of his results if taking an indicator diagram of the power required to revolve the alternator and engine empty, the conditions of full load in the alternator being, however, reproduced by Mordey's method as modified by Behrend. The errors of the indicator would only affect the efficiency in a decimated form, as claimed for Professor Threlfall's method; and engineers knew where to look for sources of error in an indicator diagram, which they would not be so prepared to do in the other test. This refers, of course, primarily to the testing of steam engines, whose brake-horse-power could be measured independently.

Dr. Sumpner Dr. W. E. SUMPNER expressed much appreciation of the great skill shown by Professor Threlfall in his experiments. The most valuable part of his investigation was not the part most prominent in his paper.

Dr. Sumpner.

The long investigation he must have undertaken in connection with the Pitot tube was one of very permanent value, and formed a much more important investigation, he thought, than that on the dynamo. In reference to the radiation of energy, Professor Threlfall assumed that no energy was radiated from the dynamo. Long before Hertz's experiments Professor Fitzgerald showed that radiation would not take place under ordinary conditions unless the frequency of the currents was over ten millions a second. One thing which struck him (Dr. Sumpner) about this test was that it could be carried on without interfering with the ordinary operations of the alternator in any way. That was a valuable characteristic, because the test must be regarded as one more suitable for the user of a dynamo than for the maker. The contractor for the dynamo was, as a rule, behind time, and when he was ready to deliver the customer was only too anxious to receive it, so that there was not much time to make tests. And this test was one which certainly would take time. It was true the observations only took ten minutes when the arrangements were made, but the preliminaries would take a long time, and he thought the test not at all suitable for the contractor's works. It was certainly a most valuable method apart from that. It was the only method he knew of in which one could apply what was practically the Hopkinson principle to a large dynamo direct-coupled to an engine. It was the only method of measuring the loss at full load in such a case. There were methods, of course, of measuring the loss at light load by using the energy of the fly-wheel and measuring the loss by diminution of the speed. But although this method now expounded had yielded splendid results in the hands of Professor Threlfall, he was in agreement with those who were of opinion that it required a great expert to make it satisfactory. What it seemed to want was some simpler method of measuring the flow of air. The temperature measurement could easily be made by boarding in the dynamo, but he was afraid the ordinary maker of dynamos would not be prepared to get the apparatus, and spend the time necessary in fitting it up in order to measure the flow of air. Like Dr. Morris, he would like some enlightenment as to the time it took to get a steady state of temperature in these measurements. Professor Threlfall's tests were remarkably accurate, and conclusively showed that the iron losses in this particular dynamo were considerably greater at full load than at no load, even when due allowance was made for extra excitation in the former case. This was due possibly to the distortion of the field.

Professor Threlfall.

Professor R. THRELFALL, in reply, said they did not use diaphragms as suggested by Mr. Lea, nor did he think they would be of any use in the distribution they had to deal with, because they had not the whirling motion. They had at other times put in mosquito netting, and in that way a standard form of distribution could be obtained with regular results. As to the use of metrical measure, he would point out that the Board of Trade unit was practically a metrical unit, and the only one which we could be considered to have in England. With regard to engine efficiency and the actual pressure on the bearings and crank-pin, they must all thoroughly agree with what had been said, but he thought

Professor Threlfall.

they were too apt to confuse a great stress with a great loss of work. There was a great stress, but the distances through which the parts moved under that great pressure were small, so that the actual expenditure of energy might be very small. His point was not that there was not a greater loss in friction at full load, but that some advantages in pumping an engine at full load were more than sufficient to compensate the greater friction losses. He regarded that as a surprising result. The indicator was not an accurate instrument, very far from it. He believed they had got out of it everything it would give them, but it was not sufficiently precise. Replying to Professor Burstall, the writer of the paper paid a tribute to the work of Heenan and Gilbert. As to what had been said regarding the difficulties of the test and the delicacy of the instrument employed, he would point out that the engineer using the test would not be expected to buy that delicate instrument. In its place he would use an instrument called a stream gauge. (Professor Threlfall showed the gauge.) All that was necessary to determine the quantity of air flowing through the pipe was to take a reading from the instrument and multiply it by the constant. Professor Burstall asked within what limits it was proved the distribution remained constant. The limits he had tested were between 500 and 3,000 feet per second. He did not know how far beyond that it would be likely to hold. He had been interested to hear what Dr. Morris had said about the methods of measuring the output of a gas-engine, but did not think observations of rate of variation of temperature would give accurate results. The length of time which was required for the temperature to become steady depended upon circumstances. They used to think five or six hours a reasonable time, but the engine was not running to waste throughout that period. He was sure any one who would give the test a trial would find it far less difficult than was anticipated. He was sorry so gloomy a view was taken by speakers as to the intellectual powers of electrical engineers. He did not know any electrical engineer worthy the name who could not make the test with the most perfect ease. The fly-wheel method of testing the efficiency would give quickly an approximate result, but it would not give results anything like as close as those he had shown. The view Dr. Sumpner took as to the cause of the extra loss had already been taken by Mr. Esson in London, and was correct. In reply to Mr. Bate, there was no shaking to give any trouble. Mr. Lindsay Forster's request for a standard system was reasonable. The thing to be standardised was, however, not the Pitot tube, but the measuring pipe. Professor Burstall had no doubt got a working method, but he would probably find that the Pitot tube was really more reliable than a large gas-meter. As to rotating anemometers he had had no experience, but every one who had used them gave them a bad character. Professor Burstall would find some interesting information in the Transactions of the American Society of Heating and Ventilating Engineers on this subject.

Resumption of Report of Ordinary General Meeting in London.

Professor Threlfall.

Professor THRELFALL, in reply, said: I will try and reply first to Mr. Esson. I had a great deal in the paper, as I originally wrote it, about the results of these tests; but I wished to bring my method before the Institution, and not the results of the method. I hope perhaps at some future time I may be in a position to do that, but I did not wish to obscure the main points by putting in details; and therefore I will only briefly say that Mr. Esson's surmise as to the *rôle* played by the field magnets was extremely pertinent. Mr. Esson seems to be rather scared by the appearance of difficulty which I am sorry to say the first presentation of the subject rendered unavoidable. I did not feel justified in bringing this matter to your notice without explaining at great length and in great detail all the elaborate precautions I had found it advisable to take to satisfy myself; but having once done it, and having once satisfied myself, I can assure you that it is not necessary to be anything like so elaborate in the matter of precautions as I have been in the case which I presented to you; and that so far from the method being difficult, anybody who can read a thermometer can apply it. Of course a careless man will get a wrong result whatever method he uses, but the chief difficulty in the method is the ever-present difficulty of measuring electrical output with accuracy. If I were starting afresh I should not consider the calorimetry of the air so difficult as the correct estimating of the output electrically; and I should be extremely sorry if, through the great weight which Mr. Esson very deservedly carries with all of us, you should any of you go away with the impression that this method is a difficult one to carry out, or contains pitfalls which are apt to trip up the unwary engineer, for such I assure you is not the case. And I should feel that any little good I might have hoped to accomplish in this paper would be gravely compromised if you had the idea that these tests were difficult to make. While I am on the subject, I might perhaps reply to a question of Mr. Mordey's. I admit that it is not a quick test, that the essence of the test is to wait until the temperature equilibrium is fixed. He asked for a figure as to the time. In the case of an alternator of the size that I dealt with—300 kilowatts—the testing would take about four to six hours. You would have to keep the generator under steady load for four to six hours in order to obtain results of the consistency and accuracy which I have obtained. If you only want rough results you need not be so careful. [Mr. MORDEY: At one load?] Yes, under absolutely fixed conditions. In this particular investigation I had to be well within 1 per cent. It is not very often necessary to be well within 1 per cent., and if you do not mind being within, say, 2 per cent. in your efficiency figure, then you can go on quite quickly and easily, and perhaps in an hour or two you can carry out a test with quite sufficient accuracy. Because, after all, when you come to deal with large quantities of heat, the thermal capacity of the materials involved is comparatively unimportant. I might also, in this connection, reply to Dr. Glazebrook, who suggested that the generator was not working

Professor Threlfall.

quite under its normal running conditions. Perhaps I did not make that quite clear. One of the points about the method is that you adjust the fans until you take air through the generator, so that the engine casing is at the same mean temperature as the engine-room, which is perhaps a sufficient answer to Dr. Glazebrook's question.

Referring now to Mr. Mordey's question as to whether the diagram of velocity distribution was through a horizontal or vertical diameter, that particular diagram is through a horizontal diameter. As Mr. Mordey pointed out, there are considerable differences above and below the centre. I selected that diagram because I considered it the limit of irregularity that you should put up with in such a measurement. It is quite easy to get the curves very much more symmetrical than that. I exhibited that as the "shocking example" which must not be exceeded in practice, otherwise you begin to get irregularities. In taking a test for the first time, you would certainly make a series of observations about two perpendicular diameters, but if the distribution of velocity is appreciably more symmetrical than is shown in that diagram, you will find there is no appreciable difference between the vertical and horizontal distribution. I think perhaps this is an answer to that question. With regard to Dr. Glazebrook's question as to where I estimated the temperature, and as to the possibility of there being a mistake in the estimation of the temperature in the outlet pipe, the temperature of the air leaving the generator was estimated while it was in motion, leaving the generator casing before it got into the measuring pipe. The temperature was independently measured in the measuring pipe for the purpose of ascertaining the density, but the stir created by the fan was so enormous that we never detected the slightest difference in the temperature across a pipe section. I was extremely interested in Dr. Glazebrook's remarks in regard to the work which is being done at the National Physical Laboratory. I can only say I am sorry I did not know about it. If it had been done three years ago it would have saved me much experimenting.

With regard to Lord Rayleigh's results, I cordially agree with everything Dr. Glazebrook said, most of which was known to me, though I did not consider that Lord Rayleigh had really given a proof, but I do not wish to introduce that subject here; and I think, with your permission, I will reserve my remarks on the subject of the measurement of air and gases, which I have considered now for three years very industriously, for another occasion, when I shall have an opportunity of dealing in detail with that part of the subject.

In reply to Mr. Chree's communication, Mr. Chree's remarks are mostly directed to questions of the theory of air measurement, and the answer must be postponed for the same reason that was given in regard to Mr. Glazebrook's remarks on the same subject. In the matter of the easiest way of applying the results of wet and dry bulb thermometer observations, each experimenter must follow his own inclination. The writer has used for many years a very convenient graphic method invented by Mr. H. C. Russell, F.R.S., Astronomer Royal of New South Wales, and in this method the "relative humidity" is the quantity directly given. Mr. Russell had his curves carefully

engraved, and the writer was so fortunate as to receive a copy. No doubt if Mr. Chree is interested in the matter Mr. Russell would be able to send him a copy of the diagram. The writer is glad to have the opportunity of acknowledging the assistance he has received from Mr. Russell's diagram—not only in the present investigation but on other occasions. Professor Threlfall.

In regard to the reliability of the thermometers employed, 0·2° C. in a range of 20° C. does not seem to be a very ambitious degree of accuracy to aim at. However, as the thermometers employed in the present case were tested at Mr. Chree's own observatory at Kew, there can be no possible question as to their sufficiency.

In reply to the general discussion in London and Birmingham, the writer desires to express his thanks to those who have taken part in the discussion, and is gratified that so much interest appears to have been aroused. It is unfortunate, however, that an impression that the experiment is a difficult one appears to be entertained by nearly all the speakers, some of whom went so far as to say that unless the writer had happened to have had some training as a physicist he would not have got through. This is possibly true for the initiation of the method, but it is not true for its repetition. At the same time, it is true that by the use of special baffles a standard distribution of velocity in the measuring pipe could be arrived at, and the necessity for a calibration done away with. The trouble of calibrating a measuring pipe is, however, trifling.

The time required to make an accurate test, *i.e.* to say 0·3 per cent. in the efficiency figure, is undoubtedly considerable, say 6–8 hours for 300 k.w., and some criticism was directed to this aspect of the matter. Such criticism is, however, not really to the point, for in testing large fly-wheel alternators, so far as the writer knows, there is no other method at all. One may not like the method of air calorimetry, it may be tedious or anything else, but at present the engineer has no choice—it is that or nothing. The efficiency of the generator tested, say 89 per cent., may, as one gentleman remarked, be a low efficiency—but in this matter what is the standard of efficiency? What published tests of large fly-wheel alternators are available? The writer knows of none—of none, that is, which are at all reliable. The fact is that designers in the absence of any experimental control have been in the habit of taking their calculated efficiencies as real efficiencies, even though it is well known that, particularly in the case of inductive loads, such forecasting is really in the nature of a pious hope. Mr. Behrend has recently drawn attention to this very matter in a paper before the American Institute of Electrical Engineers. The plain fact is that hitherto the builders of fly-wheel alternators have been at liberty to put forward pretty well whatever figures as to efficiency they were inclined to claim, and so long as the machine did

Professor Threlfall.

not get red-hot, these figures were as good as any others. As a buyer and user of alternators the writer feels that he is on much surer ground now he has a method of testing their actual performance, than he was before such a method was discovered.

The President.

The PRESIDENT: I am sure you all desire to thank Professor Threlfall for the very interesting paper he has given us, and for his equally interesting reply.

The vote was carried by acclamation.

The following paper was then read:—

"THE EDISON ACCUMULATOR FOR AUTOMOBILES."*

By W. HIBBERT, Associate Member.

The PRESIDENT: I see that the clock says 34 minutes past 9, and as there have been quite a number of demands for copies of Mr. Hibbert's paper, it is presumed there will be some discussion on the subject. I know Dr. Fleming has something to say, as he has made several tests of the accumulator. In making arrangements for the meetings, we are occasionally driven into a corner, and I find that in the present case it will be impossible to discuss this paper until about the middle of January. This unavoidable delay will give plenty of time for consideration to those who are desirous of speaking. The Council will try and arrange for the meeting to be held about the middle of January, but is unable at present to fix the exact date. I hope, under the circumstances, the arrangement meets with your approval? I am sure you all desire to thank Mr. Hibbert for what he has laid before us to-night.

The vote was carried with acclamation.

The PRESIDENT announced that the scrutineers reported the following candidates to have been duly elected:—

Members.

Robert William Frazer.
William Miles Horsfall.
John Forrest Kelly, Ph.D.
Frederic Auten C. Perrine.

Associate Members.

William James Abel.
Samuel Francis Blyth.
Frank Benedict Cramer.
Edward Neville Greaves.
Harry H. R. Green.
Edward Heitmann.
Thomas Percival Pask.
Frederick Steell Robertson.
Edward Theodor Steinthal.
Julius James S. Stuart-Fox.
Gustav Emil Unbehaun.
Charles John Wawn.
Leon Byron Woodworth.
Adolph Wunderlich.

* The Text of the paper will be printed with the Report of the Discussion upon it.

Associates.

Frederick Ibbotson Bennett.
J. Bradwell.
Alfred Edward Carr.
George Edmund Ensor.
Albert Innes.
Reginald William Newman.
John Purvis.
John Stavers.
Charles White.
Alfred Wright.

Students.

Alexander Clark.
Sidney John Eardley.
Claude Kennedy Fitzherbert.
Cornelius Henry Fox.
John Alcala Galiano.
William Lewis Harliss.
William Ernest Hean.
Alfred Harry Huddart.
Norman Neill.
George Ernest Newill.
Charles Menham Pletts.
George Francis Sills.
Francis Herbert Allen Thoday
Cecil Frushard Waddington.

The Three Hundred and Ninety-eighth (General Meeting of the Institution was the Institution of Civil Engineers, Great Street, Westminster, on Thursday December 10th, 1903—Mr. ROBERT KAY President, in the chair.

THE GILBERT TERCENTENARY COMMEMORA

PRESENTATION BY THE INSTITUTION OF ELECTRICAL] TO THE CORPORATION OF COLCHESTER OF A COMM PAINTING BY MR. A. ACKLAND HUNT, REPRESEN WILLIAM GILBERT SHOWING HIS ELECTRICAL EXPER QUEEN ELIZABETH AND HER COURT.

The President was supported by the Mayor of Westmi W. Emden), the President of the Royal Society (Sir William the President of the Société Internationale des Électricie Hospitalier), the Treasurer and Senior Censor of the Royal Physicians (Sir Dyce Duckworth, M.D.), Dr. J. Larmor (of College, Cambridge), Mr. A. Ackland Hunt (the painter of th Mr. A. R. Sillar (Borough Electrical Engineer of Colchester), Silvanus P. Thompson, F.R.S., and Mr. Conrad Cooke (Hon. S of the Gilbert Tercentenary Commemoration Fund), and M Hammond (Hon. Treasurer of the Fund), and by Members o

The Mayor of Colchester (Mr. E. H. Barritt) was also robes and chain, supported by Alderman W. Marriage, Alc Laver, and Councillor W. Gurdon Benham (ex-Mayors of C and the Town Clerk (Mr. H. C. Wanklyn).

The President.

The PRESIDENT: Mr. Mayor of Westminster, Mr. May chester, Ladies and Gentlemen,—The Council has arranged meeting of the Institution shall be divided into two parts. T part of the meeting will be devoted to the ordinary order of busin as you are all aware, our colleague, M. Hospitalier, who has from France especially for the purpose, will give us a most i lecture. I have explained to M. Hospitalier the reason for th of the meeting to-night, and he has very gracefully and kin way in the interests of the Institution.

So far as the first part of the proceedings is concerned, met to ask the Mayor of Colchester, whom we are glad t amongst us with his colleagues of the Corporation, to be kin to accept, in the name of the Institution, the picture you all se of you. The occasion is the Tercentenary of the death of Dr Gilbert. We all know something about Gilbert; but as soon concluded these few remarks, I shall place the matter in the one much more competent than I am to deal with the subject our friend Dr. Silvanus Thompson Dr. Silvanus Thompson

Dr. Silvanus Thompson.

, at Cambridge, and there are Gilbert's hand-
is therefore fitting that St. John's College should
t by its distinguished Fellow, Dr. Larmor. Col-
to-night by its worthy Mayor, Mr. E. H. Barritt,
lerk, Mr. Wanklyn, also by two ex-Mayors, Mr.
.S.A., who also is President of the Essex Archæo-
d Mr. Councillor W. Gurney Benham. Anything I
be incomplete if I did not refer to the circumstance
born at Colchester on the 24th of May, 1544, at 2.30 p.m.
a is still standing, to which he returned in his later years,
ived, and where, for aught we know, he died. That house
cca to which all electricians would go to make a pilgrim-
ain a few paces of it lie his bones in the Church of Holy
that church there is a fine heraldic monument to his
hich records his virtues and his career. Here is a photo-
t monument in Colchester. Here are photographs of his
in the books at Cambridge when he entered and was made
nd Senior Bursar. Here is the title-page of Aristotle. There
ograph of a medical certificate sent by Lancelot Browne and
dressed to the Secretary of the Queen; and there is the one
portrait that remains of him, a scarce engraving made rather
a hundred years ago from a picture at Oxford, painted in his
nd given by him to Oxford, but which, alas, disappeared from
hundred years ago.

President, I have tried to tell the tale of the hero in whose
we have met; and I hope that many of us may have the oppor-
repairing on a pilgrimage to Colchester that we may pay our
to his memory.

The President.

PRESIDENT: Mr. Mayor of Colchester, in the name of the
on, I beg to ask you to be kind enough to accept and keep
safe-keeping for your town and Corporation, the picture which
you, and which represents Gilbert showing certain electrical
nents to Queen Elizabeth and her Court.

The Mayor of Colchester.

MAYOR OF COLCHESTER (E. H. Barritt Esq.): Mr. President,
ayor of Westminster, Gentlemen of the Institution of Electrical
eers,—It is difficult for me to find the words adequately and ap-
iately to express those sentiments which ought to be expressed at
ent like the present. The kind words which have been spoken
u, Mr. President, prompted by the even kinder motive which lies
d those words, are calculated deeply to stir the feelings of a man
older than myself. And I feel, sir, it is no light task that lies
re me now. It was about a month ago that I received from Dr.
nus Thompson a letter, so unpretending, so unofficial, "a little
te and informal inquiry" he called it, asking me in a simple,
ss manner whether, in the event of any tercentenary celebration
g held in London, I might possibly be able to attend. I am obliged
wn that my thoughts turned to a dinner; and I replied: Whatever
the commemoration may take, out of respect to the memory
Dr. Gilbert, in honour of the services he rendered to electricity and
agnetism, and as the representative of his native town, the borough

The Mayor of Colchester.

in which he lived and worked and died, I should be glad to be present. I rejoice that the Institution of Electrical Engineers did not stoop to any form of celebration so transient, so mundane!

Gentlemen, we are making one another's acquaintance to-night. Perhaps, therefore, it will be fitting, if I introduce a word or two about myself in order to assure you, if assurance is necessary, that your gift comes into safe hands, and that it will remain in safe-keeping until, in my turn, I hand it over to my town. I would like to say, sir, then, with all modesty and without assumption, that twenty-seven years ago I learned to reverence the name of Dr. William Gilbert. It was then, at the age of 13, that I obtained the Queen's prize in the South Kensington Science Examination in electricity and magnetism: and, call it a coincidence or call it what you will, that prize is to-day the favourite book of my only child, a boy of 6½ summers. I remember well, when a boy, going down to the Church of Holy Trinity to see with my own eyes that mural tablet which Dr. Thompson has alluded to to-night, and I remember being turned out of the churchyard by the gardener without my desire being gratified. I remember very well my first frictional electrical machine, and how I watched the rotations of the cylinder with, I believe, more pride than I watch the revolutions of our 550-H.P. set to-day. I remember my first Leyden jar, the difficulty there was in fixing the inside coating of foil, and how I overcame that difficulty by a coating of varnish and some iron filings. I remember very well how a scarcity of pocket-money precluded the purchase of the necessary brass rod and ball for that jar, and I remember substituting a piece of stout copper wire with an oak gall stuck on the top covered with tinfoil, brought down on to the wire in order to ensure a contact. There was a battery of six Leyden jars, and I recollect taking a discharge from that battery, and for a time recollecting very little more! But I never thought, sir, how those early struggles were destined to play their part in qualifying me for the position of Chairman of the Electricity Department of the Colchester Corporation to-day, how that this would be but a stepping-stone to the high office of Mayor, how that in this capacity, representing my town, I should be invited to attend this historic gathering to-night, and receive at the hands of your President so unique a gift. Gentlemen, Colchester has learnt to reverence the name of William Gilbert, and Colchester goes out with its whole heart to you because in your wisdom, in your love, in your devotion to his memory, you have seen well to secure this valuable and historic painting, and because, having secured it, in your generosity, in your warm-heartedness you have presented it as a gift to his native town. I esteem it no light honour, nay, rather it will rank first among the many pleasant recollections associated with the opening days of my Mayoralty, the knowledge that I was privileged to attend this Gilbert Tercentenary celebration on behalf of my town, and to become the recipient, at the hands of such donors, of so cherished a gift.

Gentlemen, the painting shall find a fitting resting place upon the walls of Colchester's Town Hall, which henceforth shall become its home.

The PRESIDENT: Gentlemen, I have now to ask you to give your thanks to the Mayor of Westminster, to Sir William Huggins, the President of the Royal Society, to Sir Dyce Duckworth, the Treasurer of the Royal College of Physicians, to Dr. Larmor, of St. John's College, Cambridge, and to Mr. A. Ackland Hunt, the artist, who have been kind enough to attend this function. The President.

The resolution was carried by acclamation.

The MAYOR OF WESTMINSTER (Walter Emden, Esq.): Mr. President, Mr. Mayor of Colchester, Ladies and Gentlemen, I am sure that you will not want me to stand between you and the names that I have heard to-night not only as probable speakers, but also the gentleman who is coming before you to give you a lecture this evening; but I do feel very grateful indeed to your President and to those who have asked me to attend this evening as the representative of the City of Westminster on so very interesting an occasion as this. Undoubtedly on these occasions London can well afford to help and assist to bring about not only good feeling with the cities and towns of this great empire, but it can well afford many of the things which it would prize if exhibited in the halls of this city, and I do think it extremely generous of your Institution to give this beautiful picture into the care of the Mayor of Colchester; it is an extremely kind thing, and I think it is calculated to create and to help on that good feeling which we all wish to have as between city and city. The Mayor of Colchester has spoken in such eloquent terms, not only on behalf of his town and their gratitude, but he has also spoken in such pleasing terms of his reminiscences and knowledge in regard to matters which are more particularly your province (and which I am afraid I cannot speak of). He having done this so very fluently, I trust you will excuse me if I do nothing more than thank you very heartily for inviting me here. I hope that we, in the Corporation of Westminster, may at all times (and I am sure we shall be pleased to do so) be of service not only to this Society, but to all societies which are within the bounds of the great city. No doubt when you come to consider the large area of Westminster and its enormous rateable value, and that within it are comprised the seats of Law and of Parliament and all the great societies, it is of course to a man like myself a great honour to stand as its chief citizen or magistrate; but the honour is not one which I hope any Mayor of my city will take without also believing that he has some duties to perform in the way of assisting at any functions with any societies where he may be of service in helping the good work which those societies do. I beg to thank you very much for receiving me, and trust that I may have the opportunity of meeting you again. The Mayor of Westminster.

Sir DYCE DUCKWORTH, M.D. (Treasurer and Senior Censor of the Royal College of Physicians): Mr. President, Ladies and Gentlemen, I can assure you that I regard it as a great honour, and count myself very happy, to be present here to-night as representing the College of Physicians, of which Gilbert was so distinguished an ornament. I should like to say, first, that the President of the College expresses, through me, his regret that he is unable to be present here this evening Sir Dyce Duckworth.

Sir Dyce Duckworth.

But I feel myself very much in the right place on an occasion like this, because Gilbert was twice elected to the office which I now have the honour to hold, namely, that of Treasurer of the Royal College of Physicians. We have had this evening a short, but very brilliant account of the work of Gilbert, uttered by one who has given a remarkable amount of attention and study to his life and work—I allude to Dr. Silvanus Thompson. Those of you who know the labour he has bestowed, and the enquiries he has made, which have been most fruitful, and resulted in accessions to our knowledge of many details in Gilbert's life, which were absolutely new to us in the College of Physicians, can well appreciate the interest attaching to his three quite remarkable treatises respecting this great man. I should like to add that we, in the College of Physicians, owe him a great debt, for that work alone. We count Gilbert amongst one of the most distinguished Fellows that ever belonged to our College, and on this occasion it is a great satisfaction to me to be present here to take part in this interesting ceremonial, and I shall be happy to convey an account of it to the Fellows of the College.

The President.

The PRESIDENT: That concludes the business of the first part of the proceedings.

The Deputation from Colchester, and other guests attending the commemoration withdrew, and the minutes of the Ordinary General Meeting held on November 26th were taken as read, and confirmed.

It was ordered that the names of the new candidates for election into the Institution be suspended in the Library.

The following transfers were reported as having been approved by the Council:—

From the class of Associates to that of Associate Members—

Rowland Francis Browne. | Charles Alexander Henderson.
E. B. Schattner.

Messrs. J. Bowden and W. Henderson were appointed scrutineers of the ballot for the election of new members.

Donations were announced as having been received since the last meeting, to the *Library* from Dr. Fleming, Mons. E. Guarini, Mr. F. C. Raphael, Messrs. Rentell & Co., Mr. C. F. Smith, Prof. S. P. Thompson, and Dr. H. Wilde; to the *Building Fund* from Mr. A. T. Snell; and to the *Benevolent Fund* from Mr. R. J. Wallis Jones, to all of whom the thanks of the meeting were unanimously accorded.

The following paper was then read:—

THE SLOW REGISTRATION OF RAPID PHENOMENA BY STROBOGRAPHIC METHODS.

THE "ONDOGRAPHE" AND THE "PUISSANCEGRAPHE" (WAVE-RECORDER AND POWER-RECORDER).

By E. HOSPITALIER, Foreign Member.

As one of the oldest of the French Members of the Institution of Electrical Engineers, and as one who has always followed its proceedings with the greatest interest, the author regards it as a great honour to be permitted to place before the Institution an apparatus for which he begs the indulgence and consideration of his audience, if, by reason of its industrial and practical character, it should appear to them at all out of keeping with the scientific character of the subjects which are commonly dealt with at their meetings.

The object of the "Ondographe," and of other instruments derived from it, is to register within a reasonably long period of time (of the order of from fifteen to sixty seconds) a periodic phenomenon of so rapid a nature that the period may be as short as one thousandth of a second, or even less. Before entering, however, upon the description of the apparatus, it will be necessary to refer to certain general considerations.

The observation of a rapidly variable phenomenon may be effected with the aid of apparatus based upon two very different principles, viz.: *Direct Observation* and *Indirect Observation*.

Direct Observation.—The apparatus to be used for observation or registration should be capable of following the phenomenon instantaneously and without affecting it in any way. This result may be attained by either of two methods. That most commonly employed consists in designing the instrument so that it has a small moment of inertia, a very short natural period of oscillation, compared with that of the phenomenon to be recorded, and a degree of damping as nearly as possible critical; that is to say, it is so damped that the apparatus, when disturbed from its position of equilibrium, tends to return to that position in the shortest possible time and without over-shooting.

The second method, which is at present represented only by Mr. Abraham's Rheograph used in studying the characteristics of variable currents, involves the use of an observing instrument in which the moment of inertia is high and the natural period of oscillation is much greater than that of the phenomenon to be observed. Under these conditions the instrument would indicate something different from the phenomenon which it is wished to observe. However, it is not submitted to the action of the phenomenon itself, but to that of one more complex, which has been previously regulated in such a way that the disturbing effects due to inertia and to damping of the oscillating

system are compensated. In this way the same result is obtained as with an instrument without inertia; but these compensations at present only appear to be possible for the observation and measurement of electric currents.

Indirect Observation.—Indirect observation, based upon stroboscopic principles, is effected by reproducing the phenomenon with a much longer period, obtaining the record of the whole of its phases by taking them successively from a large number of periods. The period of oscillation peculiar to the apparatus may in this case be very long as compared with that of the phenomenon observed, provided that the duration of the total number of periods from which the different phases are collected is itself very great relatively to that of the oscillation peculiar to the recording instrument.

1.—Direct Methods.

In order that a recording apparatus may follow a given phenomenon with precision, it must satisfy the following conditions :—

(1) The period of oscillation must be very short as compared with that of the phenomenon to be studied; (2) The damping must be approximately aperiodic; (3) Disturbing causes due to the apparatus must be as small as possible; and (4) it must be sufficiently sensitive.

The first condition is realised in practice when the period of oscillation peculiar to the system of the measuring instrument is about fifty times as short as that of the phenomenon to be observed. This condition is readily satisfied when the frequency of the phenomenon under examination does not exceed from 6 to 8 per second. Beyond 500 periods per minute, the disturbance caused by the inertia of the moving parts, and the excessive or insufficient damping, render the indications illusory, unless special arrangements are made. The theoretical study of the conditions to be fulfilled has led to the development of instruments, such as the Oscillograph of M. Blondel and that of Mr. Duddell, which the members of the Institution have had the opportunity of seeing in this room.

2.—Stroboscopic or Indirect Methods.

Notwithstanding the elegance of the direct methods, and the results which have already been attained with instruments based upon them, the author is of opinion that the industrial future is reserved to the indirect methods, which have a wider field of application, and which permit of the direct recording of the phenomenon to be studied upon a strip of paper, in a way that is not possible with the direct methods, in which recourse is always had to photography.

In order to understand the principles of the Stroboscope as applied to the observation and recording of periodic and rapidly varying phenomena, the most simple of all the periodic movements may be considered, namely, that of uniform rotation. At the end of every revolution, the rotating system attains the same relative position that is

occupied one complete turn earlier. Suppose now that the system is illuminated for a very brief instant once in each revolution at the moment at which it passes a certain position, which is regarded as the initial position. The rotating system will then appear at rest. If, now, the periodic illumination be slightly retarded, so that the successive flashes follow one another at an interval of time a little longer than the period of the revolution itself, the system will be illuminated in its various phases in turn, and will appear to revolve slowly in the sense of its actual rotation. If, on the contrary, the flashes follow at shorter intervals, the system will appear to be turning in a sense inverse to that of its real rotation, since at every revolution it will be illuminated an instant before it attains the same position as on the preceding revolution. In this way the apparent velocity of rotation will have been reduced in a proportion which depends only on the acceleration or the retardation of the successive illuminations of the system.

The simplest means of obtaining these successive flashes consists in using a disc pierced with a slit as a shutter in front of a projector. The same result may be obtained by means of the sparks caused by interrupting the current through an inductance, or with alternate-current arcs, etc., but the sharpest effects are obtained with the revolving stroboscopic disc.

In order to obtain a variable difference in the periods or slip, it is possible to use an electric motor of which the speed is capable of variation—or a synchronous motor if the system is driven by a synchronous machine—which determines the measure of the slip, or a train of wheels as in the ondograph, or (the most rational of all) a differential gearing of which one of the axes is controlled by the system to be studied, whilst the other actuates the stroboscopic disc, and the crown containing the intermediate wheels between them receives from an outside source a more or less rapid movement of rotation which defines the slip. This disposition offers the great advantage of allowing the phenomenon to be apparently stopped in any specially interesting position.

The stroboscopic method is the basis of a large number of instruments which may be classed in two groups :—

A. *Stroboscopes*, or apparatus used for observations.
B. *Strobographs*, or recording apparatus.

It is proposed to limit this paper to the study of instruments of which the applications are directly or indirectly connected with electricity.

A.—STROBOSCOPES.

Stroboscopes, of which the number is infinite, do not, properly speaking, constitute apparatus, but rather experimental arrangements which are susceptible of modification depending upon the material at the disposal of the observer, and upon the research that he has in view. By way of example, reference will be made to those which the author has used for the examination of alternate-current arcs and of machinery in motion.

The Arcoscope.—A very simple experimental arrangement has been designated by this name (which is at once French and Greek), an arrangement intended to facilitate the examination of the variation in the luminosity of an alternate-current arc during a single period,—variations which it is impossible to observe directly because of their great frequency. It consists, in principle, of a small *asynchronous* single-phase, alternate-current motor, having on its axis an opaque disc provided with narrow slits placed at regular intervals, the number of the slits being equal to the number of pairs of poles of the motor. Thus, for a motor with four poles, the disc would have two slits, placed one at end of the same diameter. This motor is driven by alternate current taken from the same source as that traversing the arc under examination.

This disc, which is rotated by the motor at quasi-asynchronism, is placed in the path of the luminous rays emitted by the arc, which latter is projected by a lens upon a screen. The image of the arc is thus allowed to fall on the screen for one instant during each period, and in consequence of the slight slip of the motor when running light, the phenomena of the arc may be observed during a complete period, and this period may thus be prolonged to as much as from 10 to 15 seconds. By applying a braking action to the motor the slip is increased, and the apparent duration of the oscillation of the light of the arc is reduced. It is possible to observe the arc directly through the slits in the disc, but the result is less clear than when a projection is used and the image of the arc is magnified. If the same disc be made to carry a series of sectors, alternately white and black, the number of each kind being equal to that of the poles of the motor, and if it be illuminated by an arc- or incandescent-lamp served by the same current as is the motor, the slip of the motor may be observed and directly measured, by observing and measuring the apparent inverse rotation of the disc mounted on its shaft.

In this way it is in some degree possible to analyse the light of the arc and to judge the influence of the form of the current-curves, of the nature and quality of the carbons, of the frequency, the conditions of regulation, etc.

It is also practicable to cinematograph the phenomenon in order to be able to study it at leisure. This can be done by controlling the cinematograph by means of an asynchronous motor and photographing the arc, either directly, or after projecting it upon a screen.

Stroboscopic Transmission Dynamometer. — If a driving-shaft A actuates a working-shaft B, through the medium of a spring-coupling between the two shafts, the product of the torsional couple or torque transmitted by this spring, multiplied by the angular velocity, is equal to the power transmitted by the shaft A to the shaft B. A large number of arrangements have been devised to determine this torque, which generally shows itself in practice by a relative angular displacement of the two shafts proportional to the torque. A simple means of reading this consists in mounting a disc on each of the shafts, and in placing the rims of the two discs close together and marking on them graduations proportional to the couple exerted in each of the relative positions

of the discs. When the system is in motion, the relative displacement of the two shafts can be read off on the graduations, just as if the discs were stationary, by illuminating the system once in each revolution at the same instant in each period. For this purpose the stroboscopic eyeglass can be used with advantage.

Stroboscopic Eyeglass.—A small electric motor, driven by two accumulators, actuates a disc pierced with radial slits. The system in rotation is viewed through these slits with one eye, the other remaining closed. With the aid of a rheostat the disc may be caused to revolve at various speeds, so regulated that the system, illuminated permanently from an external source of light, appears to be either stationary or revolving very slowly. The stroboscopic eyeglass, so arranged, when brought to synchronous speed, permits the graduation of the above-described dynamometer to be observed and read with ease. If it revolves with a certain amount of retardation, it allows of the observation of rapid phenomena as readily as if they were produced at a slow speed which can be regulated at will.

All the phases of an explosion engine may, for example, be thus observed: The lifting of the valves, the contact and the ensuing vibration of the ignition cam, the formation of the stitch in a sewing machine, the starting of a part having an independent movement, etc.

Differential Stroboscope.—For the study of thermal engines, MM. Malicet and Blin have constructed for the author a special differential stroboscope in which the motor is illuminated only once in every two revolutions. This result is obtained by providing the stroboscopic disc with only one slit and mounting the disc on the crown of the differential gearing. One of the shafts of the gearing is connected by a flexible shaft to the motor engine under examination, and the other shaft, in order to produce the stroboscopic effect, may be rotated slowly by means of an endless screw controlled by a small handle turned by hand. The apparent velocity of rotation of the engine is varied by turning the handle more or less rapidly. On stopping the handle the apparent movement is also arrested.

Examples could easily be multiplied, but those which have been given suffice to show the important part that can be played by stroboscopic methods—confined, so far, to the laboratory of the physicist—in taking their places in the test-rooms of the great mechanical and electrical industries.

B.—Strobographs.

Ondograph.—The ondograph belongs to the class of strobographs. The latter name is applied to all forms of apparatus employed to record phenomena (whether rapidly or slowly variable), if they utilise the principle of the stroboscope or of successive phases. The strobographs are the result of an evolution of which M. Joubert's "point-method" constitutes the origin and the ondograph the latest development.

The object of the ondograph is to inscribe or to register directly upon a band of paper, by means of ink, the representative curves of

periodically and rapidly variable electrical phenomena (electro-motive forces, currents, differences of potential, power, etc.). In principle it is based upon a combination of Joubert's method of successive points, stroboscopic methods, and electrical recording apparatus.

Figure 1 shows the general arrangement of the actual apparatus as made by the *Compagnie pour la Fabrication des Compteurs et Matériel d'usines à Gaz*. It comprises as essential parts:—

1. A synchronous single-phase alternate-current motor actuated directly by the source of electrical energy of which the periodically variable elements are to be recorded.

2. A train of gearing of which the object is to impart to a revolving contact maker or commutator such an angular velocity that when the motor has made a certain number of revolutions, the commutator will have made an equal number (or a multiple), increased or diminished by 1. This retardation or acceleration, which is essential to the system, obviates the necessity of rotating the brushes of the motor.

3. A contact-maker or automatic commutator, consisting of a cylindrical block of insulating material carrying a tube of brass suitably cut to shape, with *three* brushes resting upon it. The object of this device is to put a condenser successively in connection with: (*a*) two points in the circuit in which the variable periodic phenomena to be recorded take place; (*b*) a measuring apparatus. During the first operation the condenser becomes charged, and is discharged through the measuring apparatus in the second. For the power-curve the contact-maker is reduced to a simple conducting bar which, once in each revolution and by means of two brushes, closes the circuit through the fine-wire bobbin of the recording apparatus. Fig. 2 shows the connections of the apparatus in the case in which a condenser is used.

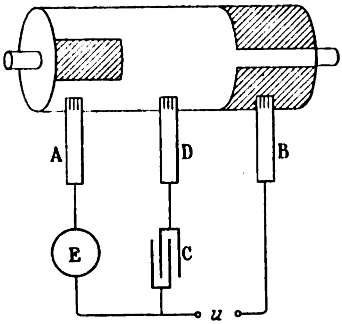


FIG. 2.

4. *A Condenser*, of which the capacity may be either constant or regulated at will by means of plugs, in order to regulate the sensitiveness of the apparatus.

5. *A Recording Measuring Apparatus*—suitable to the phenomenon to be examined. For differences of potential and currents, the recorder is a moving-coil instrument of the Meylan type, mounted horizontally.

For power-curves, the recorder is an ordinary wattmeter; the main current passes continuously through the fixed primary bobbin, whilst the movable fine-wire bobbin is placed in the circuit which is periodically connected by the rotating contact-maker to the difference of potential which determines the second factor of the power. Regulation is effected by introducing resistances into the fine-wire circuit (see below, under Power-Recorder).

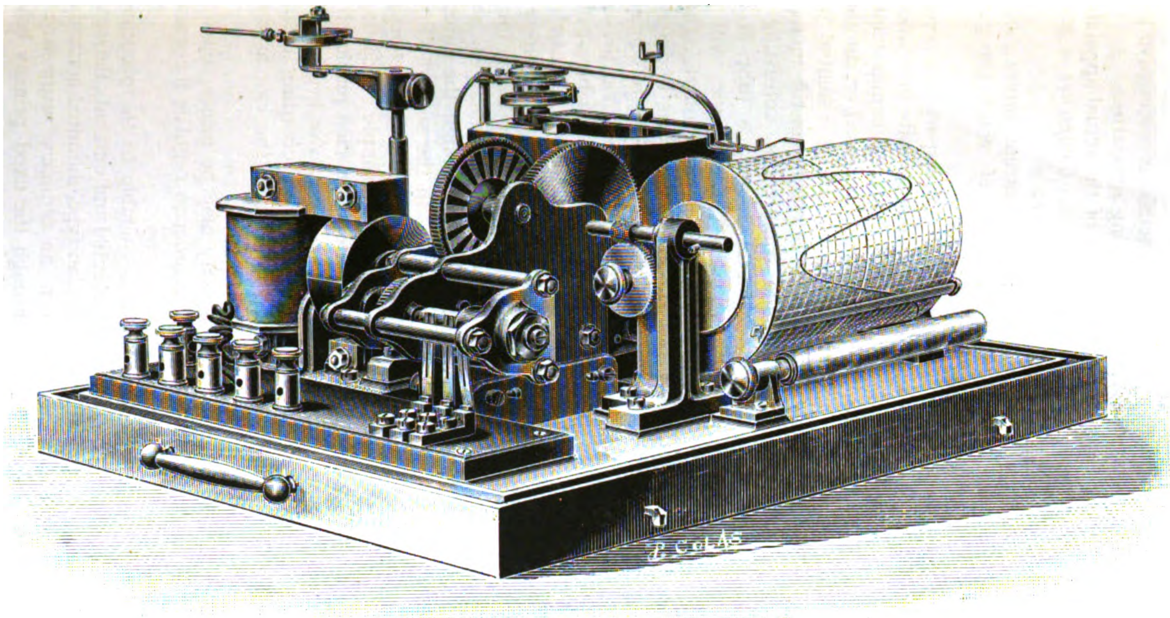


FIG. 1.—General View of the Ondograph.

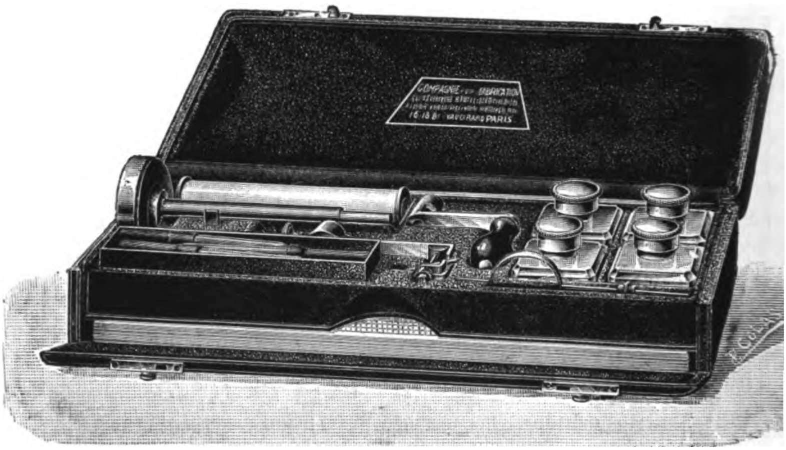


FIG. 4.—Case containing the Accessories of the Ondograph.

The direct method may also be applied equally well to the registration of differences of potential or currents, and in this case the use of the condenser is dispensed with. The condenser, however, offers distinct practical advantages in regard both to regulation and sensitiveness.

So also the wattmeter may be used for recording the curves of potential-differences, if a constant current from a battery of accumulators is passed through its fixed coils.

In all the above cases, the moving part of the recording apparatus receives a series of impulses the frequency of which is equal to that of the current to be registered. The moving-coil has a moment of inertia and damping so calculated that its position at any moment is that which it would be caused to take by the action of the mean current corresponding to the quantity of electricity passing through it during a single period.

6. *A Recorder*, either cylindrical or continuous, driven at a convenient speed directly by the synchronous motor. The record is traced by means of a pen.

The four-pole synchronous motor runs with a potential-difference of 110 volts at frequencies ranging from 25 to 100 periods per second. The motor is started up by means of hand gearing, and; when synchronised, is thrown into circuit. The precise moment at which the current should be switched on is determined by the stroboscopic effect of the apparent stoppage of a disc revolving with the motor and carrying a suitable number of black and white sectors painted alternately. After the motor has been started, the hand gearing is disengaged automatically by an arrangement similar to that adopted for use in automobiles.

The motor actuates the commutator by a train of gearing so combined that when the motor has made $\frac{n}{2}$ revolutions, corresponding to n periods, the commutator will have made only $\frac{n-1}{2}$ revolutions, with a regular and uniform retardation.

The recording cylinder makes one complete revolution for every three periods. Each of the three curves registered corresponds to 1,000 periods and 999 impulses. One complete period takes up a length of 96 mm. on the cylinder. The amplitude may be made to vary, at will, between 10 and 50 mm., by altering the potential difference and the capacity.

The ondograph allows the frequency of an alternating current to be determined with accuracy. To effect this it is only necessary to determine by means of a chronometer the time occupied by the recording cylinder in making one complete revolution. As this time corresponds to 3,000 periods, this number divided by the duration of one complete revolution in seconds gives the frequency in periods per second.

Fig. 3 is a plan of an ondograph, drawn to a scale of one-fifth, showing the arrangement of the apparatus. Fig. 4 shows on a one-third scale the case containing the accessories, viz., long pointer, stand,

handle, red and black ink, oil, alcohol for cleaning the pen, spare pen paper, etc.

In most recording instruments in which direct tracing is effected, i is necessary to reduce the length of the pointer that carries the pen ir order that the friction of the pen on the paper may not sensibly falsify the record. The use of a short pointer in the ordinary way, necessitatec

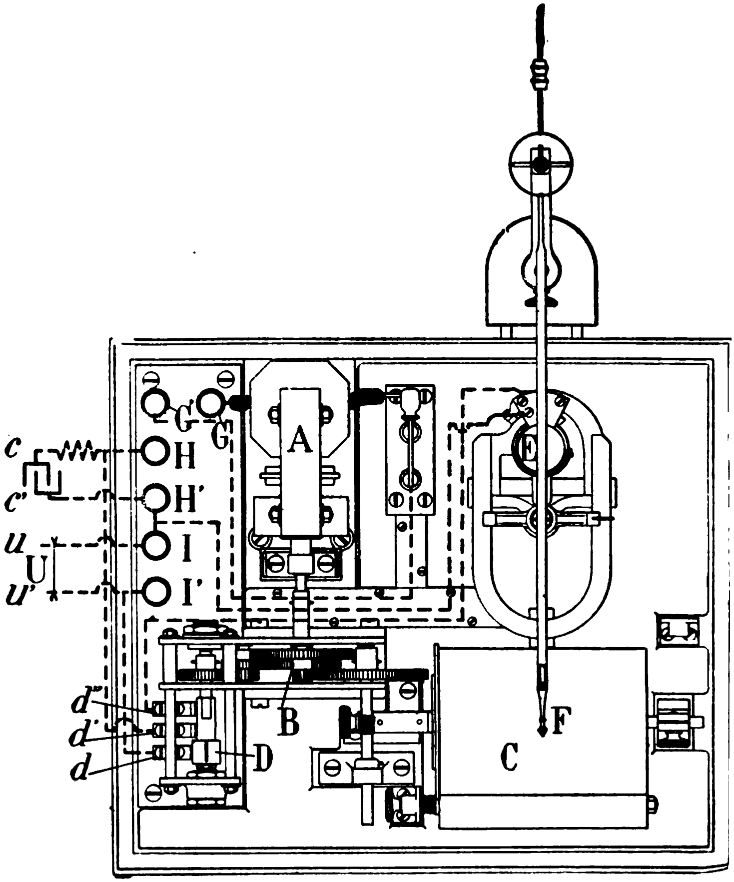


FIG. 3.—Plan of the Ondograph.

by the smallness of the directing force and the friction of the per gives rise to several inconveniences:

(1) The curvilinear ordinates have a relatively short radius of curva ture, and the curve recorded therefore is subject to a deformation tha is often troublesome;

(2) The curvilinear trajectory of the pen prevents it from accuratel

touching with equal accuracy at every point of the recording cylinder, of which, if the radius were infinite, it should describe a generatrix. Under these conditions a pen correctly regulated only records by points in certain positions, presses strongly upon the paper in other positions, and again, does not rest upon the paper at all in positions corresponding to the longest ordinates.

(3) The arm carrying the pen should be both rigid to enable its direction to be controlled well, and flexible to facilitate its record; it is difficult to combine these two opposite qualities in the same mechanism.

In order, in a large measure, to reduce these difficulties, the author has adopted an arrangement which consists in principle in the separation of the mechanisms for guiding the operator and for recording, without impairing their capability of joint action; and in obtaining, with a guiding system of short radius, a record in which the radius of the ordinates is so great that the record approaches sensibly to that which would be afforded by a registering pointer of which the pen would describe an arc of a circle having an infinite radius.

The recording apparatus comprises two distinct parts: the directing arm and the recording pen. The former is a rigid lever attached to the measuring apparatus, with the extremity the more remote from the axis of rotation terminating in a pin which works in a groove provided upon the lever carrying the pen. This pin, during the recording process, describes the path that would be taken by the pen of an ordinary recording instrument during the rotation of the cylinder carrying the paper.

The recording pen consists of a lever of great length, so arranged that one of its extremities turns upon an axis parallel to that of the recording instrument, but removed from it by a distance approximately equal to the difference in the lengths of the two levers. The other extremity is provided with a groove engaging with the pin of the directing arm, and carries the recording pen at a point a little beyond the groove. In the actual ondograph, the directing arm is 18 cm. long, whilst the lever carrying the pen is double this length, namely, 36 cm.

It will be understood from this that whilst the pin describes an arc of a circle with a short radius, the pen describes one of long radius. By giving sufficient length to the lever the arc may, within the limits of the width of the cylinder, coincide sensibly with the tangent at the middle point of the arc. Thus, the point of contact of the pen with the paper is but very slightly removed from a generatrix of the cylinder, and the registration is effected with perfect regularity throughout the whole extent of the cylinder. The pen and its lever can therefore be proportioned so as to satisfy all the necessary conditions as to flexibility and regulation of the recording mechanism, and of this part of the apparatus only, since the pen is directed by another mechanism to which in turn it is easy to impart all the rigidity necessary to fulfil this function satisfactorily.

The lever is attached at its point of support by a Cardan joint which allows the pen to move freely and to exert upon the paper a constant pressure regulated by its own weight, in part counterbalanced by a screw-counterpoise movable at will. The vertical axis allows for the

movement caused by the directing arm, whilst the horizontal axis permits the slight vertical displacement resulting from that of the pen moving over the recording cylinder. The curve is thus inscribed almost exactly on the generatrix of the cylinder, and the pen, which acts independently and is easily regulated, is not liable to fail in its record.

The ondograph may also be used to study rectified or continuous currents. To accomplish this the synchronous motor is replaced by a direct drive, effected by establishing an unyielding mechanical coupling between the ondograph and the shaft of the machine to be studied. The apparatus has been designed with a view to facilitating and expediting the work of removing or replacing the motor; the motor having been removed, a flexible shaft is placed in position with one of its ends attached to the ondograph, and the other upon the machine under examination.

Non-Periodic Phenomena.—The application of the ondograph, or speaking more generally, of stroboscopic methods, is not limited to periodic phenomena. It can be extended to all phenomena of short duration, provided that the phenomenon can be reproduced identically in such a manner that it is periodic by repetition. By way of example, reference may be made to the curve of discharge of a condenser through a self-induction, a discharge which is of an oscillatory character. The duration of each semi-oscillation is about $\frac{1}{400}$th of a second. By means of the differential-movement ondograph, permitting the retardation at will of the period recorded, it is easy to register phenomena occupying from $\frac{1}{1000}$th to $\frac{1}{3000}$th of a second, obtaining the record by means of a pen upon a strip of paper—a result which has never hitherto been obtained.

Differential Ondograph.—In the apparatus which the author has just described, the slip or retardation which allows of the registration of the curve bears a fixed relation to the frequency of the phenomena to be recorded. It is characterised by the number 1000 in all the apparatus made by the *Compagnie pour la Fabrication des Compteurs.* That is to say, when the frequency is 25 per second, the record is effected in 40 seconds ($25 \times 40 = 1000$); when the frequency is 50 per second, the record requires 20 seconds ($50 \times 20 = 1000$), and so on. The recording cylinder, of which the circumference is 288 mm., corresponds to three periods, each occupying 96 mm. along the axis of time.

In a new type which is styled the *Differential Ondograph*, in order to indicate the principle upon which it is based, the period of registration is no longer connected directly with the frequency. On the contrary, it is entirely independent, and further, the drum registers only two periods, so that each of them is 144 mm. long. This increase of the axis of time facilitates the determination of the phase-difference between the different curves representing the characteristic factors of the phenomenon recorded.

The apparatus still consists of a synchronous motor and a commutator, arranged coaxially, and between them is a differential gear, the crown of which is rotated around the axis common to the motor

and commutator by means of an endless screw, turned more or less rapidly by hand. The shaft carrying this endless screw is also provided with a second endless screw, which rotates the recording cylinder with an equal angular velocity.

Under these conditions, remembering the well-known properties of the differential gearing, it will be understood that if the crown is stationary the motor will drive the commutator at synchronism. If the crown be subjected to a displacement in either direction, the commutator will be accelerated or retarded accordingly in proportion to the amount of this displacement. The apparatus is so arranged that the direction of rotation suitable to recording upon the drum produces retardation. This retardation will correspond to one complete revolution of the commutator, that is, to one period, for each half-revolution of the crown and each half-turn of the recording-drum. By the time that the crown of the differential gear has completed one revolution the commutator will have suffered a retardation equal to two revolutions, and the recording cylinder will have made one turn, and in doing so will have recorded two periods. As the slip of the contact and the retardation of the drum are controlled by hand, the record of a single period may be produced as slowly as may be required without being correlated with the frequency of the phenomenon under examination.

It is possible to dispense with hand control by employing either an auxiliary motor driven electrically, or by means of a spring, or by using direct control by means of gearing, or a series of stepped pulleys by which different speeds may be obtained by the shifting of a cord which passes over two of the corresponding pulleys.

This type of ondograph does not in the author's view lend itself for industrial use, but is rather an instrument for use in the laboratory or for research. The author has employed it in studying commutation in continuous-current dynamos, in such a way that he could follow the smallest variations—variations for which the period traced with 999 points for 1000 periods did not afford a sufficient approximation.

Puissancegraphe (Power-Recorder).—The author has applied the principle of the ondograph in designing the apparatus, which is intended to trace direct the curve of the instantaneous value of the power expended in a circuit, and to which he has given the name of the Puissancegraphe.

In order to trace the curve of the instantaneous power supplied in any circuit by means of the ondograph, a Thomson meter used as a wattmeter is substituted for the moving-coil galvanometer. The spindle of the meter is controlled by two special springs which act as conductors through which the current flows in and out of the movable armature, thus avoiding the use of brushes.

The main current traverses the fixed coils, and the movable fine-wire coil is connected by means of the commutator and the brushes as a shunt to the potential-difference determining the power to be measured, for a very brief interval, once during each period. For this purpose the rotating commutator consists of an ebonite cylinder in

which is embedded along a generatrix a plain strip of brass of suitable width.

The duration of contact is governed by the width of the strip. It may be modified at will by shifting the points of contact of the two brushes with the strip. The regulation of the period of contact allows of a change in the sensitiveness of the apparatus, an effect which may also be obtained by introducing a variable resistance into the fine-wire circuit of the wattmeter. The coil, under the influence of the successive impulses which it receives from the intermittent currents passing through it and from the main alternating current, is deflected from its position of equilibrium through an angle, proportionate to the power at each instant of the period determined by the position of the commutator; either directly or indirectly the coil guides the pen of the recorder.

This proportionality results from the fact that the angle described by the moving-coil around its position of equilibrium never exceeds from 10° to 12° on either side of zero. Under these conditions the drum-wound armature of the wattmeter may be considered as having suffered no practical displacement as far as electro-dynamic forces are concerned.

The aluminium damping disc of the meter serves to give to the system the inertia and damping necessary to the normal working of the apparatus. This normal working corresponds on the one hand to the critical damping, and on the other hand to the time of oscillation of the armature, being comprised between the periodic time of the phenomenon to be recorded and the time occupied in recording a complete period.

The "puissancegraphe" has enabled the author to obtain on the same sheet of paper curves showing the instantaneous values of the potential-difference, and the current, and also their product—the instantaneous power—in an alternating circuit. This was accomplished as follows: It has been shown that the "puissancegraphe" traces out the instantaneous power, by joining (for a very short time during each period) the potential-difference to the moving-coil of a wattmeter the fixed coil of which is traversed by the alternating current. The impulse is proportional to the product, $v\,i$, of the difference of potential at that instant (v), multiplied by the instantaneous value current (i), and the instrument traces the curve of instantaneous power. In order to trace the curve of i, it is sufficient to connect the commutator to a constant potential-difference V. The impulses are then proportional to $V\,i$, or that is to i, since V is constant. To obtain the curve v, a constant current from one or two accumulator cells is passed through the fixed coils, and the commutator is connected to the difference of alternating potential v. The impulse is then proportional to $I\,v$, that is to v, since I is constant.

The ondograph is especially useful to manufacturers of dynamos, motors, and transformers; to alternating-current generating stations; to makers of high-tension cables, to whom it is important to know the wave-form of the alternating current to which their cables will be subjected; and to technical schools, to research and teaching laboratories, as it renders visible at a glance many facts of which the explanation is often both difficult and troublesome.

APPLICATIONS OF THE ONDOGRAPH.

In order that this communication may not be unduly prolonged, we will at once proceed to a description of some of the uses to which the ondograph has been put with the object of studying or of improving the working conditions of apparatus designed for the production and distribution of electric energy.

ALTERNATORS.—Alternators should, in principle, give a sine-curve, or approximately a sine-curve, as free as possible from higher harmonics, so as to avoid those resonance effects which are so prejudicial to cables. The curves reproduced in Figs. 5 to 8 prove that this is far from being the case. Some of them show the influence of the shape of

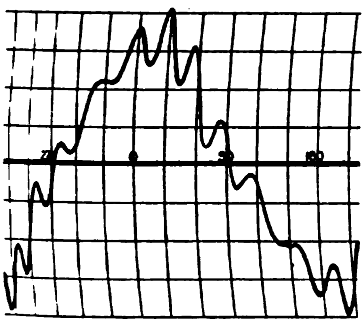


FIG. 5 (Half-scale).—Alternator working on Cable Mains.
Kilowatts = 220
Amperes = 110
Cos ϕ = 0·66

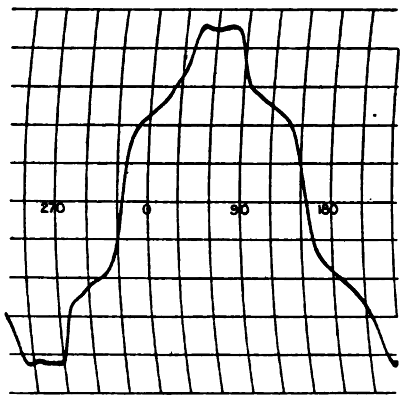


FIG. 6 (Half-scale)—Berlin (Siemens & Halske) old Alternator, November 7, 1903.

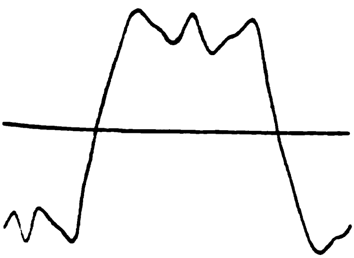


FIG. 7 (Half-scale). — Three-phase Oerlikon Inductor Alternator; with two slots per period per phase, and laminated pole-pieces.

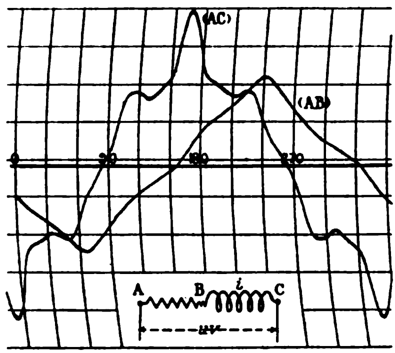


FIG. 8 (Half-scale).—Monocyclic Alternator working on a Self-induction.
(A C) Difference of Potential.
(A B) Current in the Self-induction.

the pole-pieces, which introduce the third and fifth harmonics, whilst others exhibit the effect of the teeth. A careful study of these curves makes it possible so to alter either the pole-pieces or the number or shape of the teeth that these objectionable distortions are greatly reduced. These curves are, of course, of an exceptional shape, and selected mainly for illustration of the registering qualities of the ondograph.

REACTION OF THE ALTERNATING-CURRENT ON THE EXCITATION.—It is well-known that the armature current in an alternator reacts on the field and produces in it a varied magnetisation, with a frequency double that of the alternator. This effect is exhibited in Fig. 9, which shows the potential-difference between the terminals of a Siemens alternator with an iron-less armature, when working on an inductive-circuit and producing a current with a lag of about one quarter of a period. The wavy line, representing the exciting-current, would be straight were it not for the reaction of the armature. This effect becomes more pronounced with an increasing lag of the current behind the electro-motive force of the alternator.

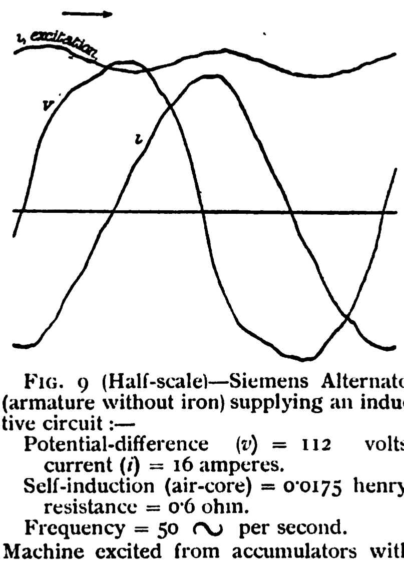


FIG. 9 (Half-scale)—Siemens Alternator (armature without iron) supplying an inductive circuit:—
Potential-difference (v) = 112 volts; current (i) = 16 amperes.
Self-induction (air-core) = 0·0175 henry; resistance = 0·6 ohm.
Frequency = 50 ∿ per second.
Machine excited from accumulators without any resistance in series:—
Exciting current = 23 amperes; resistance of circuit = 0·4 ohm.

ROTARY CONVERTER.—Fig. 10 shows the variation in the difference of potential between the terminals of a two-phase rotary converter. This curve has been repeated five times to demonstrate that the small changes caused by hunting do not alter the general appearance of the curve.

THE SYNCHRONOUS MOTOR OF THE ONDOGRAPH.—This little motor works as a variable self-induction motor having a very large difference of phase, well shown in Fig. 11, which gives the difference of potential v, and the current i at each instant.

BRUSH MACHINE.—The current given by a very old Brush machine is shown in Fig. 12, which was obtained by driving the ondograph direct from the machine with the aid of a flexible shaft. This figure exhibits the amplitude of the variations in the electro-motive force caused by the passage of each elementary coil under the pole-tips. The machine was supplying arc-lamps.

THE DETERMINATION AND RECORDING OF HARMONICS.—It may be admitted in principle that an alternating wave-form contains all the odd harmonics with larger or smaller amplitudes, and zero amplitude for

those that are absent. The first problem to be solved consists, therefore, in discovering the order of the highest harmonic present. Calling the pulsation of the fundamental wave ω ($\omega = 2\pi$ frequency) and the order of the harmonic n, it is required to determine n, that is to say, to discover the order of the highest harmonic.

Determination.—The author employs two methods, the one based on the properties of a circuit having capacity, the other on those of an inductive circuit.

Capacity Method.—As large a capacity as possible is connected to the

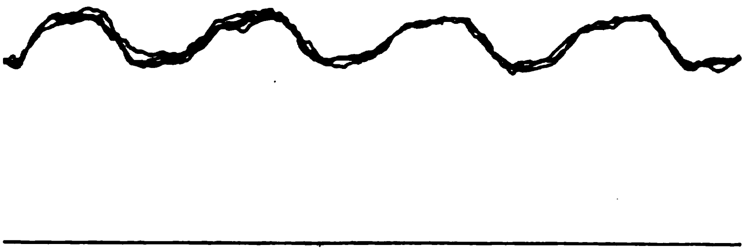


FIG. 10 (Scale 1 : 1).—Difference of potential between the terminals of a two-phase Alioth Rotary Converter on open circuit. Secteur de Neuilly. Curve repeated five times.

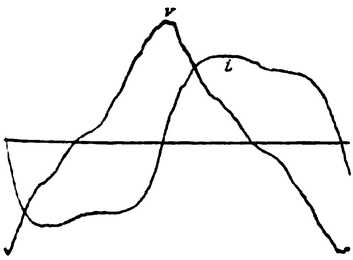


FIG. 11 (Half-scale).—Potential-difference (v) and Current (i) Wave-forms of the Ondograph Synchronous Motor.

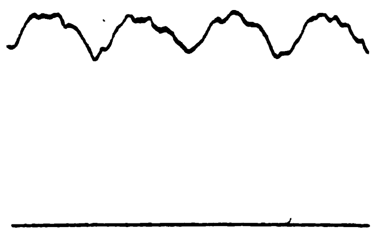


FIG. 12 (Half-scale). — Current given by Brush Machine supplying Arc-lamps.

periodic potential-difference to be analysed, and the curve of the charging-current of the condenser is recorded by connecting the ondograph to the terminals of a non-inductive resistance included in the circuit through which flows the charging current of the condenser. This resistance should be as small as possible. Designating the effective (r.m.s.) difference of potential corresponding to the nth harmonic V_n, the corresponding effective current I_n for this harmonic may be expressed thus:—

$$I_n = n \omega C V_n.$$

Hence, by this method, the nth harmonic is magnified in proportion to its order n, and an indented curve is obtained in which the number of

teeth indicates the order of the highest harmonic with the greatest clearness. Fig. 13, for example, shows very clearly the discovery of the 15th harmonic in the *Secteur de la Rive gauche*, a harmonic that the sinusoïdal looking potential-difference would not have enabled one to predict.

Self-induction Method.—A circuit, formed of a highly-inductive coil, having as long a time-constant as possible, and a non-inductive resistance, is connected to the terminals of the difference of potential to be analysed.

The difference of potential V_s between the terminals of the inductive coil may be approximately expressed as follows, if its resistance may be neglected as compared with its self-induction :—

$$V_s = n\,\omega\,.\,L\,.\,I.$$

By using the ondograph to record the instantaneous values of the potential-difference between the terminals of the self-induction, an indented curve is obtained analogous to that given by the charging-current of the condenser, and the order of the highest harmonic is readily deduced from this curve.

Record.—When the order n of the highest harmonic is once known, it is easy to trace the fundamental wave and all the harmonics with their several amplitudes, actual or enlarged in a given proportion, as well as their difference of phase relative to the curve under analysis.

The method employed by the author is that given by Professor Pupin * in 1894. It consists in forming a resonating circuit for each of the harmonics, using the recognised relation—

$$n^2\,\omega^2\,L\,C = 1,$$

with a variable condenser and capacity connected in series and as a shunt to the difference of potential to be analysed.

If the resistance R of this circuit is sufficiently low, when resonance is obtained for a harmonic of the order n, the impedance offered by the circuit to all the other harmonics is considerable, and the current passing through the circuit is exactly due to the nth harmonic, defined by the relations—

$$V_n = R I_n \; ; \quad \tan \phi = 0.$$

With an ondograph that has been calibrated beforehand, the instantaneous values of I_n can be recorded, and from them V_n may be deduced. In order to make sure of the resonance of the harmonic, a determination is made of the theoretical value that must be given to the product L C, corresponding to the frequency; L and C are then added to satisfy this; finally, L and C are varied slowly in the neighbourhood of the theoretical value, until a thermal amperemeter placed in the resonating circuit indicates the maximum current.

* I. PUPIN, "Resonance Analysis of Alternating and Polyphase Currents," Amer. Inst. E.E., May 17, 1894.

With the aid of the Ondograph this resonance is confirmed by the amplitude and regularity of the sinusoïdal curve, a curve which becomes deformed by the interference of the next harmonic.

To show the lower harmonics, of which the amplitude is usually sufficiently great, the ondograph may be connected to the terminals of a non-inductive resistance placed in the resonating circuit. The curve traced by the ondograph is in phase with the harmonic.

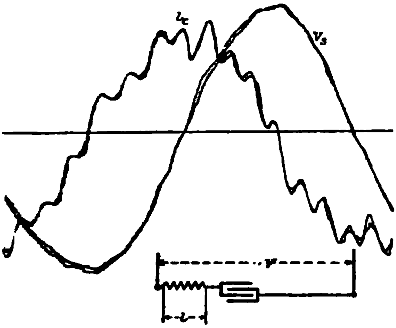


FIG. 13 (Half-scale).—Charging of a Condenser :—
Capacity = 16 microfarads.
Potential-difference = 110 volts.
Resistance in circuit = 20 ohms.

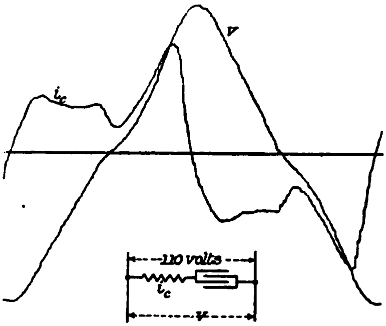


FIG. 14 (Half-scale)—Charging of a Condenser (Zipernowsky machine, without slots) :—
Capacity = 16 microfarads.
Potential-difference = 110 volts.
Resistance in circuit = 20 ohms.

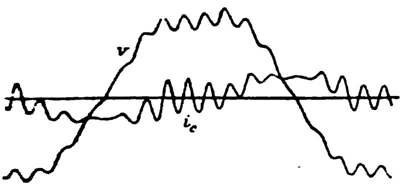


FIG. 15 (Half-scale).—Labour Alternator (old type), with 18 teeth per cycle, Ring.
Potential-difference between the terminals (v) = 95 volts.
Capacity current = i_c.
Capacity = 3·5 microfarads.
Resistance in circuit = 50 ohms.

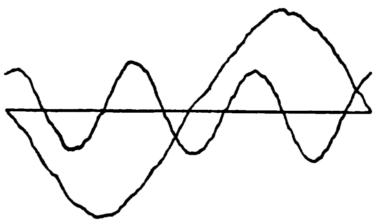


FIG. 16 (Half-scale).—Resonance of Third Harmonic :—
Capacity = 2·45 microfarads.
Resistance = 6 ohms.
Self-induction = 0·76 henry.
Frequency = 40·4 ∿ per second.

The sensitiveness would not be sufficient for higher harmonics of small amplitude. It is therefore augmented by means of a device which consists in recording the difference of potential between the terminals of the self-induction instead of between those of a resistance placed in the circuit. Under these conditions a much greater potential-difference is obtained, and the curve traced by the ondograph shows

a difference of phase in advance from the actual harmonic to an extent defined by the relation—

$$\tan \phi = \frac{n \omega . L}{R}.$$

In practice, $n \omega$ L being very large and R comparatively small, tan ϕ is also very large, and the curve recorded is thrown out of phase, showing a lead of a quarter of a period. It is therefore important to keep this phenomenon in mind when it is desired to reconstruct the fundamental curve synthetically.

It would also be possible to obtain a record of the higher harmonics by connecting the ondograph between the terminals of a capacity, in which case the curve traced would show a lag of a quarter of a period. It is, however, preferable to connect the instrument between the

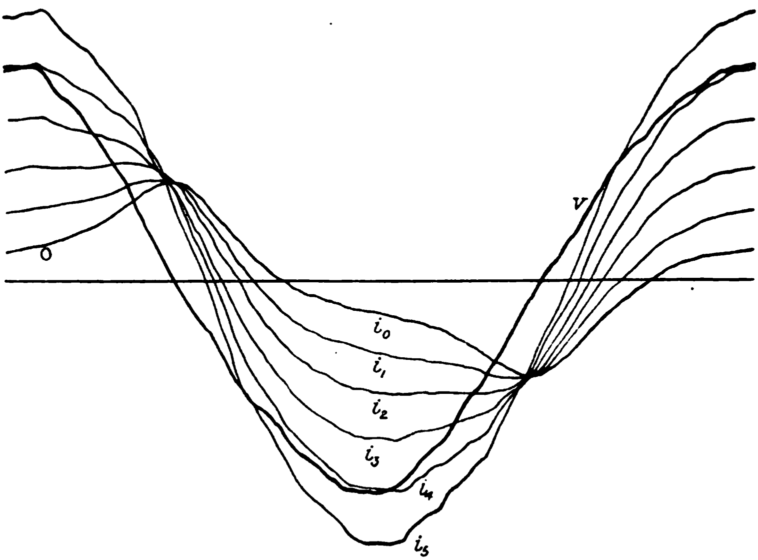


FIG. 17 (Scale 1 : 1).—Gaulard Transformer.

terminals of the self-induction in order to avoid the sparking at the brushes of the apparatus at the moment when the measuring capacity is shunted upon the resonating capacity, which charges it too suddenly.

Figs. 13, 14 and 15 relate to the determination of the highest harmonics of a difference of alternating potential by means of the charging-current of a condenser connected to that difference of potential. It will be seen from Fig. 14 that only the third and fifth harmonics are present, whereas the curve shows the fifteenth harmonic. Fig. 16 shows the third harmonic resonated, and so accentuated.

Transformers.—Fig. 17 illustrates the variations in the primary

current of a Gaulard transformer, of which the secondary is connected through a gradually diminishing non-inductive resistance. The successive curves show the increase in the primary current accompanying the increase of charge in the secondary, as well as the diminution in the difference of phase.

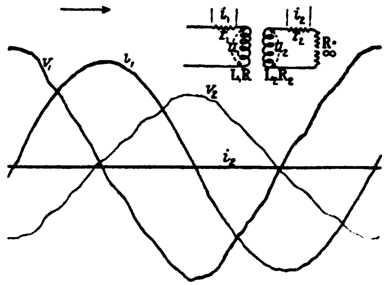


FIG. 18 (Half-scale).—Study of an Ironless Transformer.

Fig. 18 relates to an ironless transformer. v_1 is the difference of potential acting on the primary circuit; i_1 is the primary current rendered almost completely sinusoïdal by the influence of self-induction; v_2 is the potential-difference between the terminals of the secondary or open circuit, in opposition to the potential-difference of the primary.

Electrolytic Rectifier.—Fig. 19 refers to a Nodon valve arranged as a Wheatstone's bridge and working on a circuit consisting of a simple resistance. v is the difference of alternating potential supplied to the valve, and i the rectified current supplied by it. Fig. 20 relates to a valve feeding a circuit consisting of a battery of accumulators. Curve 1 is the primary potential-difference, and curve 2 the primary current. Curve 3 is the secondary current as rectified, whilst curve 4 is the potential-difference between the terminals of the accumulators during

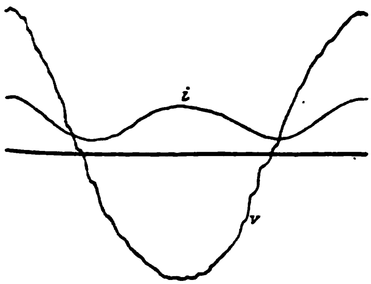


FIG. 19 (Half-scale). — Electrolytic Rectifier, connected up as a Wheatstone Bridge, supplying current to a resistance. Supplied by Secteur Rive Gauche.

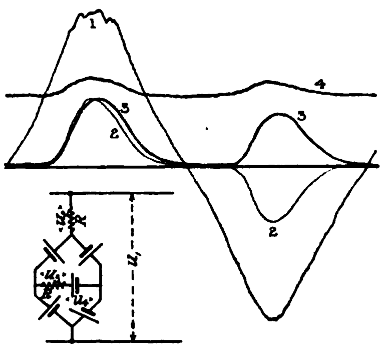


FIG. 20 Half-scale).—Nodon Valve connected up as a Wheatstone Bridge. charging accumulators.
1 = Potential-difference of supply.
2 = Current.
3 = Current, rectified.
4 = Potential-difference of accumulators, r.m.s. current = 11 amperes.
Mean current rectified = 9 amperes.

the charge. From this it will be seen that charging takes place twice during each period.

It would be easy to multiply the number of curves, showing the application of the ondograph to the study of the Wehnelt interrupter, the continuous-current arc, rectifiers, the oscillatory charge and discharge of condensers, polyphase currents, the simultaneous record of potential-difference, current, and power in an alternating circuit, etc., etc. The author's collection of curves obtained during the last two years embraces specimens referring to all the above applications, but those which are here reproduced suffice to indicate the wide scope of the instrument, and it would be an encroachment upon the hospitality of the Journal of the Institution of Electrical Engineers to increase still further the number of the reproductions.

ADDENDUM,

RELATING TO PREVIOUS WORK IN THE SAME FIELD.

The origin both of the stroboscopic method of observation and of the method by successive points is lost in obscurity. The application of the latter method to the study of alternators is, however, due to M. Joubert.* The condenser was applied by the author in 1885† to the study of the rectified currents obtained from M. Anatole Gérard's dynamo.

At the meeting of the *Société française de Physique* of March 20, 1891, M. G. Weiss stated that he was employing an apparatus to determine by points, or in continuous fashion, the shape of the wave of a dynamo, but he failed to describe the apparatus.

M. Blondel, at the meeting of April 17, 1891, claimed to have invented a recording apparatus with successive contacts, involving the charging and discharging of a condenser. This apparatus has since been constructed and described.‡

M. Blondel's apparatus traces the curves satisfactorily, but it reproduces them by photographic means, and not by tracing them directly with ink upon a recording cylinder. Again, the brushes are movable whilst those employed by the author are fixed, and the apparatus requires as many galvanometers as there are curves to be traced, whilst the author's apparatus uses but one recorder for all the curves. M. Blondel's apparatus is direct-driven by the generating dynamo, whilst the author's is driven by a synchronous motor, which allows of the instrument being rapidly set up at any point in the electric circuit, and dispenses with the clockwork movement of the stroboscopic arrangement.

* J. JOUBERT, "Études sur les machines magnéto-électriques."—*Ann. de l'École normale supérieure*, 1881, vol. 10, p. 151.

† E. HOSPITALIER, "Les machines à courant périodique et leur mesure."—*L'Électricien*, December 19, 1885, vol. 9, p. 853.

‡ A. BLONDEL, "Sur la détermination des courbes périodiques des courants alternatifs et leur inscription photographique."—*La Lumière Électrique*, 1891, vol. 41, pp. 401 and 507.

In Herr F. Drexler's apparatus* the slip is obtained by means of an asynchronous motor, and the record is obtained by means of sparks. The slip of an asynchronous motor is, however, too variable and too great to be employed satisfactorily for direct stroboscopic recording, and the arrangement does not allow of the exact determination of the phase-relations of curves traced successively, since the slip is not kinematically connected with the rotation of the recording cylinder.

Mr. F. A. Laws† replaces the asynchronous by a synchronous motor and imparts a slight angular retardation to the brushes by rotating them by means of suitable gearing. The record is still photographic.

The first apparatus tracing an alternating-current curve directly upon a recording cylinder is that of Professor H. L. Callendar.‡ This apparatus is based upon the principle of the potentiometer, and of Professor Callendar's well-known relay-recorder with auxiliary motive-power. The cylinder is rotated by clockwork and the record of a curve is completed in an hour, whilst the author obtains the same record in from ten to thirty seconds.

The ondograph differs from the preceding apparatus in that it traces a continuous curve on a recording sheet without the aid of photography or of clockwork, without relay, without rotating the brushes, and without depending upon the very variable slip of an asynchronous motor running light.

The author believes the *Puissancegraphe* (Power-recorder) to be absolutely new, for he has not found any reference to such an apparatus in the literature of Electricity.

The PRESIDENT: I am sure we are all very much indebted to our friend, M. Hospitalier, for his discourse on the various instruments which lie on the table, and for the experiments and illustrations he has made. His remarks have been more in the character of a lecture than a paper for discussion; but if Mr. Duddell, who has had the opportunity of helping, as he always does with great good heart, in the translation of M. Hospitalier's paper made by our Secretary, Mr. McMillan, has something to say, we shall be very glad to hear him. The President.

Mr. W. DUDDELL: I think I am expressing the feelings of this meeting by thanking Professor Hospitalier for coming to England and bringing his most interesting instrument to show us, and for all the trouble he has taken in preparing his paper, and more especially for giving it in English, in our own language. I regret very much that Professor Hospitalier had to give it us in English. It is our loss that we have had to ask him to read it in English; but Professor Hospitalier speaks our language so very much better than I fear myself and many others of us understand French, that he kindly consented to give the Mr. Duddell.

* F. DREXLER, "Über eine neue Methode zur selbstthätigen Aufzeichnung von Wechselstrom-Curven."—*Zeitschrift für Elektrotechnik*, 1896, vol. 14, part [8], p. 237.

† F. A. LAWS, "An Apparatus for Recording Alternating Current Waves." —*Western Electrician*, February 23, 1901, vol. 28, p. 128.

‡ HUGH L. CALLENDAR, "An Alternating Cycle-curve Recorder."—*The Electrician*, August 26, 1898, vol. 41, p. 582.

Mr. Duddell paper in English, and I am sure we all desire to compliment him on the admirably clear way in which he has done so.

Personally, I am extremely interested in this instrument. I have devoted a considerable amount of time to tracing the wave-forms by what M. Hospitalier calls the direct method; and I am very pleased to see that the indirect method has now been brought to a really satisfactory point, so that you can simply switch the apparatus on, as he has done, and obtain the curve at once without having any complicated or trying scientific apparatus to set up. I think I may say that many experimenters have built apparatus to endeavour to do this, but I do not remember having seen an instrument that worked in public so extremely smoothly and satisfactorily under the trying conditions of a lecture, where you are away from your laboratory, as this apparatus has done. M. Hospitalier has shown us some extremely interesting curves on the screen. Curves of resonance effects have been shown (shown at this Institution when Mr. Field's paper was read) which M. Hospitalier has admirably recorded with his instrument—effects which are extremely difficult to record by any point to point method, owing to the extremely variable nature of the phenomena. Many of these resonance effects, when they are at all sharp, are very transitory. A small change in the speed of the machine will alter the frequency of the higher harmonic and spoil the resonance, and spoil your record altogether; and I think it is greatly to the credit of M. Hospitalier's machine that he has succeeded in giving us these beautiful records of resonance effects. Another very difficult thing he has recorded is the wave-form of the alternate-current arc. That is a very variable phenomenon, and to get so good a record is an achievement. The discharge of the condenser is also a very difficult thing, but it is a thing which you can more or less control, as you can have it in your laboratory, and spend as much time as you like in making its repetition accurate. That you cannot do with the arc, because it does not do what you wish it to do.

In conclusion, I should like to compliment M. Hospitalier on the most admirable piece of apparatus he has shown us, and to thank him, as I am sure you all do, for the trouble he has taken in coming over here and reading this paper before us to-night.

Professor Ayrton. Prof. W. E. AYRTON: I thoroughly agree with what Mr. Duddell has said, that M. Hospitalier has accomplished a great feat in producing the apparatus that he has shown us to-night, and I join with him in expressing the thanks of the Institution for the most delightful and, may I say, the most exciting evening we have had in this room for a long time.

Mr. Stoney. Mr. G. STONEY: I have seen a good deal of Mr. Duddell's most interesting oscillograph, and M. Hospitalier's ondographe is certainly most interesting also. I am speaking now as a rough-and-ready electrical engineer; and I want something that will give me alternator curves that I can put into the hands of a test-house staff. I do not think either the oscillograph nor—excuse me saying it—M. Hospitalier's most interesting ondographe is fit for such work. Oscillograph work has to be done by skilled men accustomed to the work; but if anybody

could produce a thing which would give alternator curves that I could put into the hands of our common testing-house staff, it would be of great advantage to electrical engineers. Mr. Stoney.

The PRESIDENT: I am afraid I cannot invite anybody else into the arena of discussion, so there is very little for M. Hospitalier to reply to. I can only ask you to show in a very hearty manner your appreciation of what M. Hospitalier has done for us this evening. The President.

The motion, conveying thanks to M. Hospitalier for his paper, was carried by acclamation.

M. HOSPITALIER having expressed his thanks for the reception of his paper, the President announced that the scrutineers reported the following candidates to have been duly elected:— M. Hospitalier.

Members.

Francis Hird, B.A. | Alexander George Ionides, B.A.

Associate Members.

John Addison. | Constantine Manuel.
William John Mitchell.

Associates.

Edward Butler.
Francis Dickinson.
James Zachariah George.
Frank C. Harding.
Will de Manoel Landon.
George Newby.
Charles Newton.
Andrew Mackie Niven.
Robert Watson.
Ernest H. Wyndham Westwood.

Student.

Alfred Carleton Blyth.

NOTICE.

1. The Institution's Library is open to members of all Scientific Bodies, and (on application to the Secretary) to the Public generally.

2. The Library is open (except from the 14th August to the 16th September) daily between the hours of 10.0 a.m. and 6.30 p.m., except on Saturdays, when it closes at 2.0 p.m.

An Index, compiled by the late Librarian, to the first ten volumes of the Journal (years 1872-81), and an Index, compiled under the direction of the late Secretary, to the second ten volumes (years 1882-91), can be had on application to the Secretary, or to Messrs. E. and F. N. Spon, Ltd., 125, Strand, W.C. Price Two Shillings and Sixpence each.

A further Index, compiled by the Secretary, for the third ten volumes (years 1892–1901) is now ready, price Two Shillings and Sixpence, and may be had either from the Secretary or from Messrs. Spon.

Publishers' Cases for binding Vol. 32 of the Journal can now be had from the Secretary or from Messrs. Spon, price 1s. 6d. each.

JOURNAL

OF THE

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The Three Hundred and Ninety-ninth Ordinary General Meeting of the Institution was held at the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, December 17th, 1903—Mr. ROBERT KAYE GRAY, President, in the chair.

The Minutes of the Ordinary General Meeting held on December 10th, 1903, were by permission of the meeting taken as read, and signed by the President.

The names of new candidates for election into the Institution were taken as read, and it was ordered that they should be suspended in the Library.

The following transfer was published as having been approved by the Council :—

From the class of Associate Members to that of Members :—

William Ransom Cooper.

Donations were announced as having been received since the last meeting to the *Library* from Messrs. C. Naud, J. H. Rider, and James Roberts ; and to the *Building Fund* from Mr. C. Manuel, to all of whom the thanks of the meeting were duly accorded.

The following paper was then read in abstract :—

THE CITY AND SOUTH LONDON RAILWAY: WORKING RESULTS OF THE THREE-WIRE SYSTEM APPLIED TO TRACTION, ETC.

By PETER VALENTINE McMAHON, Member.

In presenting this paper on the City and South London Railway the author feels that, notwithstanding the number of articles and illustrated descriptions which have appeared in the technical press, both when the line was first opened and upon the occasion of the opening of its extension, a very full description of the plant should be given, in order that the tests and working results which follow may prove more useful to those interested.

As this line is the pioneer of deep-level railways and also of heavy electric traction, a few early details may not be out of place. The line was opened for traffic on December 18, 1890, with terminal stations at Stockwell and King William Street, City, with a total length of $3\frac{1}{2}$ miles. The power-house at Stockwell contained three vertical compound engines driving by link-belts and jockey-pulleys, three Edison-Hopkinson generators having an output of 400 amperes at 500 volts. A fourth engine and generator were added shortly after the opening and, later, a high-speed Willans-Siemens set was put down, which was also the first direct-coupled engine and generator to be used for traction purposes in the United Kingdom. Steam was supplied by eight Lancashire boilers 7 ft. 6 in. diameter by 28 ft. long, fed by Vicars mechanical stokers and working at 140 lbs. pressure. Six of these boilers were in use, the remaining two being spares. The pumping engines for the hydraulic lifts were also worked from the same boilers. In the first year of working 5,261,398 passengers were carried. Some figures as to the working of this plant are given later.

With the experience gained in the nine years' working of the railway from Stockwell to King William Street, when the question of additional power for the extensions of the line to Clapham Common and Moorgate Street and the later extension to Islington were considered, it was decided to build a new generating-station and to convert the old one into a repair and tool shop. It was also found that to meet the growing traffic it would be necessary to run four-coach instead of three-coach trains as in the past. The lifts on the old line were worked by hydraulic mains from Stockwell, the pressure at the generating-station being 1,240 lbs. per square inch. The working of these lifts had given the greatest satisfaction in every possible way in the past, but the problem of transmitting the necessary hydraulic power to Islington involved a radical alteration in the hydraulic plant, and so the question of electric lifts was gone into. At this time the largest electric lift made only carried eight or ten persons, and the directors, on the recommendation of the author, agreed to alter one of the existing hydraulic lifts to work electrically. The result of the experiment was satisfactory, and it was decided to use electric lifts on the extension.

With the increased length of line, quicker service, and heavier trains, and with the lifts worked electrically, it was clear that the plain

two-wire distribution at 500 volts continuous-current would not meet the case from the point of view either of economy or of the Board of Trade regulations. All possible systems were considered, and it was decided to adopt the continuous-current three-wire system with the rails as the middle wire. Doubts were expressed in some quarters as to such a system meeting the conditions, but the result of working has shown that the choice was a happy one.

The new generating-station was built on a piece of land adjoining the old boiler-house at Stockwell, and consists of a steel and brickwork structure with slated roof. It is capable of being extended to at least double its length for any future extensions. The engine-room measures 186 feet in length by 55·5 feet in width, and the boiler-house is 36 feet wide and, of course, the same length.

The depôt at Stockwell is unfortunately not close to a main-line railway station or the river, and so all the coal has to be conveyed a certain distance by carts. Experience in the old station showed that it was highly important, when using small coal with mechanical stokers, to be able to separate the coal in bunkers and to get any particular kind of coal easily to the stokers if necessary, and the new handling and storing arrangements of coal were designed accordingly.

On arrival, the coal is weighed on an ordinary weighbridge and tipped into the elevator pit outside the boiler-house, whence it is carried up to the roof of the boiler-house by a 12-inch bucket elevator and distributed to the various bunkers by a 15-inch push-plate conveyor. As shown on Fig. 1, the coal bunkers are arranged in two rows with a gangway between, the large bunkers being 24 feet by 20 feet wide, and the small ones 24 feet long by 11 feet wide; they are all 8 feet in depth. The floors are not made sloping, on account of the loss of capacity by such an arrangement, and very little additional labour is involved on this account, as the bunkers are kept fairly full and the coal then falls to the front and through the opening in the side to the shoots leading to the stoker hoppers. The small bunkers are used for storing a better quality of coal, usually peas, and should the North-country or Midland coal which is stored in the large bunkers prove to be inferior, it is only necessary to open the sliding door on the small bunkers and to adjust the large bunker opening to get the desired mixture. This arrangement has proved very satisfactory in practice, and has on many occasions saved a lowering of steam-pressure through the North-country coal not being as good as it looked. As an additional safeguard a pair of tram-lines and a small trolley opening at the bottom runs along the gangway between the bunkers, so that in the event of any individual small bunker getting emptied the good coal could be easily transferred from the other end of the floor. The push-plate conveyor only extends over the boilers Nos. 1 to 10, the others, west of the elevator, being supplied by a screw-conveyor. This latter portion was added for the Islington extension, and as in all probability the extensions of the railway are not yet complete, more boilers and another elevator will be added at the extended end of the boiler-house, when the push-plate conveyor will take the place of the screw. Both the elevator and conveyor are driven by a 16-H.P.

Westinghouse motor, but it only requires 8 H.P. to drive them, and the motor is therefore large enough to drive the mechanical stokers should the steam-engine break down. In a like manner the engine is capable of doing the double duty should the motor fail.

After leaving the bunkers, the coal descends by gravity through measuring shoots to the mechanical stoker hoppers on each boiler. The construction of these shoots is such that it is not possible to let the coal run through without being measured, as the hole in the top slice is closed before the hole in the bottom slice is opened. Each pull of the hand lever is recorded on the dial, and the coal used entered in the log at the end of each shift. The shoot holds 170 lbs. and is fairly accurate when compared with the coal delivered at the end of the half-year, the error not exceeding 1½ per cent. The first nine measuring shoots erected had an arrangement for adjusting the capacity of the chamber, but this was found unnecessary and was not used in the remainder.

In front of the boilers an ash-trolley tipping sideways runs on rails, by which the ashes are tipped into a pit and lifted into an ash-tank outside the boiler-house by an 8-inch bucket-conveyor. This ash-bunker holds about 30 tons, and the ashes are removed by carts, which are backed under and filled from the bunker with a minimum amount of labour. The whole of the plant for handling the coal and ashes was erected by the New Conveyor Company, Smethwick, and has, so far, been very satisfactory. It may be said, however, that the upkeep of the ash-elevator is greater than that of the rest of the plant, on account of the grinding action of the ashes upon the sliding guides.

The boiler-house contains twelve Economic boilers 15 ft. 6 in. by 8 ft. 9½ in. diameter, built by Messrs. Davey Paxman & Co., of Colchester, the rated evaporative duty of each boiler being 8,000 lbs. of steam per hour; and two almost similar boilers by Messrs. Taylor & Sons. These boilers have fewer tubes and no cross-tubes in the flues. The setting is of the standard type used with this style of boiler, but the main flue is in front on account of the position of the chimney. The chimney is 160 feet high, and is 8 ft. 6 in. in diameter at the top. The main flue is divided into sections by dampers, with manholes for inspection, cleaning, and repairs, and tapers between Nos. 1 and 5 boiler only; it is then carried through the length of the boiler-house in full section. This arrangement was adopted to allow of extension and the erection of an additional chimney when required. The mechanical stokers are of the well-known Vicars type, and are driven by an 8-H.P. compound-engine built by Messrs. Davey Paxman. The boilers are fed by a duplicate range of feed-pipes from four Weir pumps, two of which are capable of doing the work; the valves, etc., are so arranged that any pump can be used to feed either range of feed-pipes independently. The condensed water from the hot well is treated with alumina-ferric: this curdles the oil, which is then pumped into a tank in the filter-room over the pumps, where some of the oil floats to the top and is collected, the water is then passed through a Masson & Scott automatic washing sand-filter which removes every trace of oil; it is then with the additional make-up water sent through a Chevalet & Boby heater

detartariser, which heats the water to boiling-point and also softens it down to about 4 degrees of hardness: this amount of course can be varied by the quantity of soda used. It was found in working that a fair amount of fine matter in suspension was carried into the boilers, probably on account of the want of more settling room in the detartariser, and so another self-washing sand-filter was inserted between the detartariser and the feed-pumps. Considerable attention was given to the question of a satisfactory water-meter when the station was designed, but an all-round satisfactory meter was not to be found that would work with hot water under boiler pressure. The Weir pumps were fitted with counters, and this, it was thought, would give accurate results, if the pumps were kept in good order. It was found, however, that this method of measuring the feed-water represented a very high duty in the boilers—in fact, too good to be true, hence special measuring-tanks were erected. Upon calibrating the pumps it was found that during certain hours of the day the number of pounds of water delivered for each stroke of the pump varied, depending upon the speed of the pump; but this variation was fairly constant from day to day—*i.e.*, during the hours of heavy load the number of pounds of water per stroke was practically the same each day, but when the load was lighter and the pumps ran slower, the amount pumped per stroke was less. However, taking an average value per stroke over the whole day, a fairly accurate idea of the working can be arrived at, and this method was found to be accurate enough to detect any variation in the amount of water evaporated. The tests which are given later are, however, taken from the actual tank measurements.

Steam is taken from the range of boilers by a duplicate system of steam pipes, one range in the boiler-house and the other in the engine-house. Instead of keeping one range spare, both pipes are always in use, and thus in case of a joint blowing out or other accident to the main, it is only necessary to shut down the defective main, the other being already working, and no time is lost in heating up a cold main. This arrangement exposes more surface, but the amount of steam piping is reduced to a minimum, and with good lagging the loss is very small. In addition, the arrangement of the two mains in use at once admits of the pipes being smaller, and as one main is only used in cases of emergency, any wire-drawing of steam due to the use of one smaller pipe is more than counterbalanced by the other advantages.

In the engine-house, at present, seven direct-connected sets are installed, varying in output from 125 to 800 k.w. It will no doubt occur to many that with large Corliss engines the sets might have been larger, and therefore a smaller number of engines and generators would have been required for the same output—say, three 800-k.w. sets, working at 1,000 volts across the outer, with a couple of small sets at 500 volts for balancing. A moment's reflection will show that, with a generator running at 1,000 volts across the outers, a permanent short-circuit on one side of the system could raise the pressure on the other side to 1,000 volts, and this, even if momentary, would not improve train lamps, and lift and locomotive motor armatures, not to speak of the danger to men operating switches, etc., on that side of the system.

For this reason, primarily, it was decided to adopt the method of two 500-volt generators with the middle point connected to the running rails (or middle wire of the system). Further, this method and the sub-station reducers allow all the advantages of a 2,000-volt continuous-current distribution in which no commutator has more than 500 volts maximum across its brushes.

Going more into the details of the engine-house equipment, the units are divided up as follows: Two Willans engines direct-connected to 125-k.w. generators, one a Siemens bipolar set which ran for about six years in the old generating-station. This, as before mentioned, was the first direct-connected high-speed set used for traction work in the United Kingdom; the successful running, close-governing, and small repairs of this set led to the adoption of Willans engines in the new station. The second small Willans engine is coupled to a 125-k.w. E.C.C. four-pole generator. The next size is 300 k.w., and two 3 R Willans engines are coupled to 300-k.w. E.C.C. generators.

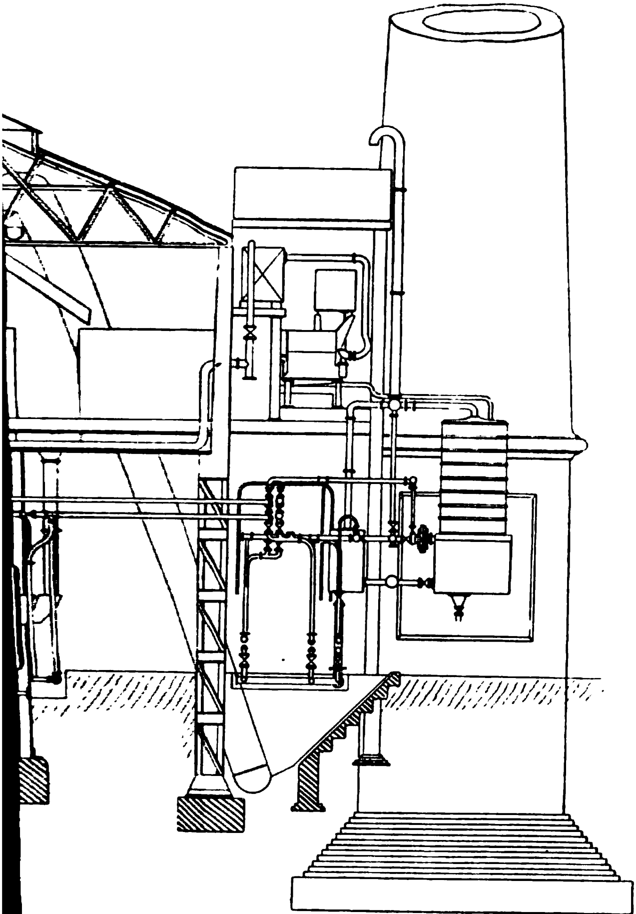
The larger sets consist of two 800-k.w. E.C.C. generators direct-coupled to Corliss engines made by Messrs. Cole, Marchant & Morley, of Bradford, the last set installed being a Ferranti-E.C.C. direct-connected set of 400 k.w. capacity. The experience gained in running the Willans and Corliss engines showed that there was a decided economy in steam consumption in favour of the latter engines, and in all probability another Corliss engine would have been put down, but for the high first cost of a fairly small set as compared with that of the high-speed sets. The Ferranti engine, however, seemed to combine the advantages of the Corliss in the matter of valve-gear and steam-consumption, while its speed brought the price to that of a Willans direct-coupled set, the floor space occupied being, if anything, less than by the Willans set of the same output.

The details of the Willans engines are so familiar to all electrical engineers that it is unnecessary to go fully into them, but a few leading dimensions may be interesting. The two smaller sets, known as the 11 S, have two cranks set at 180° apart and give 210 I.H.P. when running at 350 revolutions per minute with a steam pressure of 150 lbs. per square inch, condensing.

The diameters of the high-pressure cylinders are 14 inches and of the low 20 inches, with a stroke of 9 inches.

The guaranteed steam consumption with a vacuum of 23 inches was as follows:—

	B.H.P.	lbs. of steam per. I.H.P.	lbs. of steam per B.H.P.
Most economical load 120–125 k.w.	180	17·75	20·0
Maximum load 150 k.w.	220	18·00	20·0
Three-quarter load	140	18·00	21·0
Half load	100	19·00	23·5



Londoн Railway.

The second size, known as the 3 R, have three cranks at 120° apart and give 500 I.H.P. when running at 320 revolutions per minute. The diameters of the high-pressure cylinders are 440 mm. and of the low 720 mm., the stroke being 260 mm.

The guaranteed steam consumption was as follows :—

	B.H.P.	lbs. of steam per I.H.P.	lbs. of steam per. B.H.P.
Most economical load 320 k.w. ...	470	16·5	18·5
Maximum load 400 k.w.	585	16·9	18·5
Three-quarter load	363	16·75	19·25
Half load	260	19·0	23·5

It is satisfactory to be able to state that upon test the engines came out better than the maker's guarantee.

The Corliss cross-compound engines, as already stated, were made by Messrs. Cole, Marchant, & Morley, Bradford, and their general construction can be seen from Figs. 1 & 2. The engines run at 85 revolutions per minute and develop 850 brake horse-power at most economical load and 1,160 B.H.P. at late cut-off. The high-pressure cylinders are 24 inches in diameter, and the low-pressure cylinders 48 inches, with a stroke of 4 feet. The flywheels are of peculiar construction, being built up of boiler plate carefully dished, so that the wheel somewhat resembles a bicycle wheel in shape. This construction gives a remarkably safe wheel with a maximum weight in the rim where it is required. The diameter of the wheels is 24 feet, and they weigh 38 tons each. The total weight of the flywheel, armature, shaft, and cranks is 80 tons per engine. The peripheral velocity of the flywheel at 85 revolutions per minute is 106 feet per second, and has a stored energy of 4,600 foot-tons. The calculated factor of safety of the wheel is 20.

The guaranteed steam consumption was as follows :—Most economical load 16·3 lbs. of steam per brake horse-power, at 25 per cent. overload 17·5 lbs., at three-quarter load 17·5 lbs., and at half load 20 lbs. It was, of course, impossible to test these engines at the maker's works, but when tested at Stockwell the results were well within the guarantee. Reference is again made to the steam consumption of these engines, and the voltage charts show their governing capabilities on a traction load.

The seventh set is a Ferranti-E.C.C. cross-compound engine, also direct-coupled to a 400-k.w. E.C.C. generator running at 250 revolutions per minute. The diameter of the high-pressure cylinder is 20 inches and that of the low-pressure cylinder 36 inches, with a stroke of 15 inches. The flywheel weighs 18 tons. The guaranteed steam

consumption was 14·85 lbs. of steam per I.H.P. per hour at full load, and 14·6 lbs. of steam per I.H.P. per hour at three-quarter load.

GENERATORS.

With the exception of the Siemens generator which was removed from the old station, all the new machines are multipolar, and made by the Electric Construction Co., of Wolverhampton.

The 800-k.w. generator attached to the Corliss engines have armatures 10 feet 8 inches in diameter, and their weight (without shaft) is 28 tons. The field magnets are divided into four portions to facilitate handling, and have 14 poles, the compound-winding being on alternate poles. The machines are compounded to give a steady pressure of 500 volts at the switchboard 'bus-bars and have a commercial efficiency of 94 per cent. at normal full load.

The 300-k.w. generators are almost similar to the above, the armatures being 4 feet 2 inches in diameter, and the magnets split across the horizontal diameter; they have 6 poles. The commercial efficiency of these generators is 93 per cent. at normal full load.

The 125-k.w. generator is similar to the 300-k.w., only differing in size, having 4 poles, and a commercial efficiency of 92 per cent. at normal full load.

The 400 k.w. generator is built to the same general specification as the 300-k.w. machines, the armature being 4 feet 2 inches in diameter. The magnets have 6 poles, and are split across the vertical diameter to allow of ready handling.

Each generator is capable of developing the normal full load continuously with a rise of temperature not exceeding 60° F. measured under Admiralty conditions. With an overload of 33 per cent. for one hour, the rise does not exceed 70° F.

In the case of the 800, 400, and 300 k.w. sets, the armature is bolted directly to the flywheel as well as being keyed to the main shaft.

The old Edison-Hopkinson generators which were originally belt-connected to Fowler engines and supplied current for the railway from the opening until the new generating-station was built, were removed to the new station and coupled up as motor-generators. These machines, together with Nos. 1, 2, 3, 4, can be used on the high-tension service for feeding the sub-station; but reference will be again made to this.

In the generation-station a double booster is erected opposite No. 5 generator; this booster was installed to compensate for the voltage drop in the Kennington feeders, but unless in cases of very heavy loads it is found that the voltage on the line is so steady that the booster is not run continually.

CONDENSING PLANT.

All the engines exhaust into a cast-iron main 32 inches in diameter, which rises above the roof of the finished end of the engine-house. This pipe is fitted with an automatic relief-valve which opens to the atmo-

sphere upon the pressure in the main rising to a few pounds, and remains open until the vacuum is restored and the valve set by hand.

The condenser is of the "surface" type, has 2,080 tubes, ⅝ inch in diameter, and 14 feet 2½ inches long. The air pumps are of the Edwards type, steam-driven by high and low pressure cylinders so arranged that one or both cylinders can be used at high pressure or run independently in case of a failure of one pump. Two centrifugal circulating pumps force the circulating water through the condenser and over the cooling towers. One pump is steam-driven by a Bumsted & Chandler engine, which was removed from the old station, and the other by an E.C.C. series-motor of 60 B.H.P. Either pump working singly is capable of dealing with the present load, but the piping, etc., can accommodate both pumps working together.

There are two cooling towers, the larger one (a Klein tower) is divided into three compartments, which can be operated singly or together, and is capable of taking care of the full load. The other tower was designed by Mr. Druitt Halpin, and is of entirely different construction. This tower is circular and is built up of steel angles and corrugated galvanised iron sheets, and the water, instead of falling over a series of laths or hurdles, is forced upwards from the bottom through a series of small nozzles. Outside of each nozzle is placed a cast-iron pipe somewhat similar to a 7-inch drain-pipe contracted at the waist, and a sort of injector action for the air is formed. The only drawback to this form of tower is the liability of the nozzles to become stopped up with oil and dirt, but this applies more to the case of a jet than to a surface condenser.

With the exception of this tower the whole of the condensing plant and piping was supplied by Messrs. Cole, Marchant & Morley, Bradford.

The Three-Wire System.

Before referring to the switchboard it will perhaps be well to decribe briefly the three-wire system, with the arrangement of 2,000-volt distribution to the sub-station, which in reality is a sort of 5-wire system.

It will be remembered that the old line from Stockwell to King William Street, a distance of 3 miles 12 chains, was successfully worked on the plain two-wire system for nine years, but with the extension to the Angel, coupled with a quicker service and heavier trains, it was necessary to abandon this method of distribution with all its simplicity.

Before coming to a decision in the matter all possible systems were carefully considered, and it seemed to the author that the three-wire system with accumulator sub-stations would satisfactorily meet the case. After a couple of years' experience with this system it can fairly be said that the City and South London Railway is a successful example of continuous-current distribution at high voltage.

The diagram Fig. 3 shows the system in its simplest form—that is, all the independent cables for supplying the lifts and lighting circuits are omitted for the sake of clearness. The up- and down-working conductors with the running rails as the middle wire form the 3-wire system

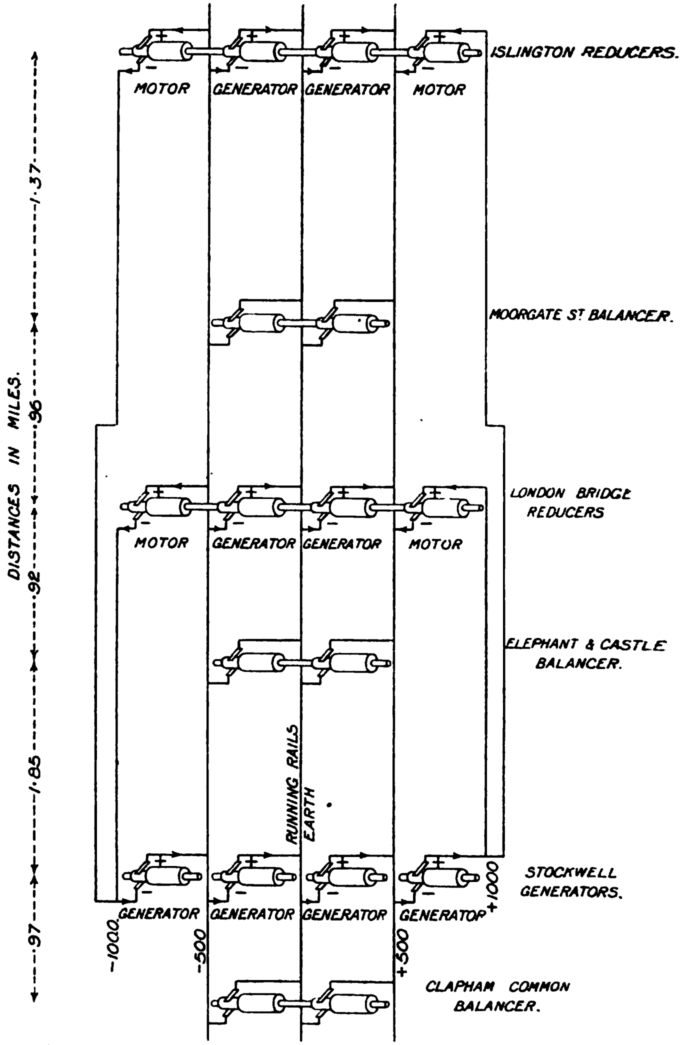


FIG. 3.—Diagram of System, lift- and lighting-cables omitted.

Note.—To simplify the diagram the reducers at the sub-station are shown as having four armatures. Each reducer has two double-wound armatures.

pure and simple, the 500-volt generators being on either side of the system. To supply the sub-station, another generator, either steam- or motor-driven, adds an additional 500 volts to an additional set of high-tension 'bus-bars from which the two sub-stations are fed at 1,000 volts above the rail potential, or 2,000 volts across the others. The pressure is reduced at the sub-station by special E.C.C. reducing transformers in which only half the energy is transformed and the cable drop compensated for.

In the old days the steadiness of the light in the carriages was far from satisfactory, and this was due in a great measure to the bad governing of the main engines and to the drop in the cables and small working conductor. When designing the new plant great stress was laid upon having an absolutely steady voltage on the working conductor under all conditions of load. In the first place very close governing of the engines was insisted upon and fortunately obtained, as shown by the recording voltmeter charts on the switchboard. Fig. 4 shows that the voltage is

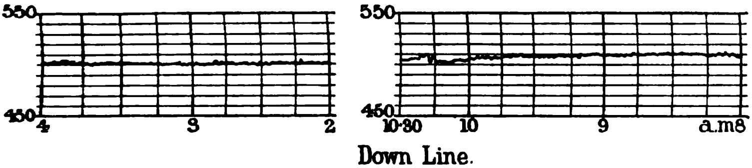


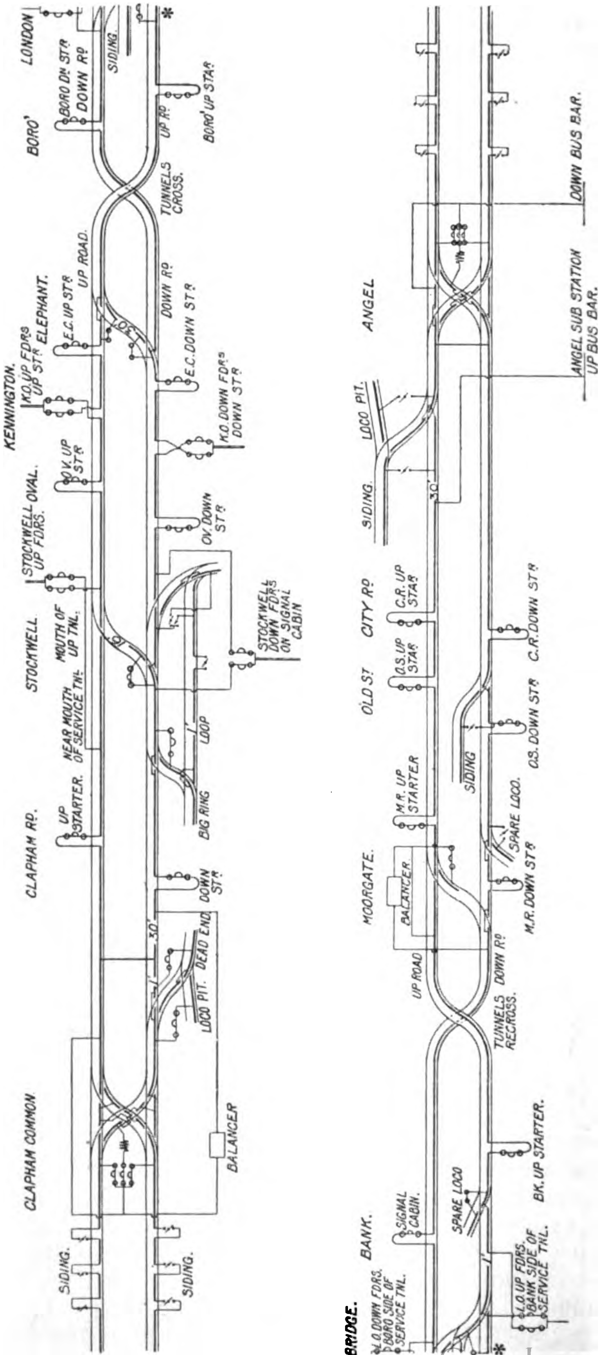
FIG. 4.—'Bus-bar Volts, 8–10.30 a.m., and 2–4 p.m.

absolutely steady under all conditions of load. Having a steady voltage at the generating-station switchboard, it was decided to repeat this at various points along the line.

The first feeding-point chosen was Stockwell, where the voltage drop between the working conductor and the switchboard was practically nil. The next point is Kennington, 1·31 miles from Stockwell. In connection with this feeder a double booster is installed to compensate for the feeder drop, but, as already mentioned, this is a refinement which is only used in case of extra heavy traffic, or if it is desirable to reduce the load on the London Bridge sub-station for any reason.

The above sub-station, 2·77 miles from Stockwell, forms the third feeding-point, and the Angel sub-station, 5·12 miles from Stockwell, is the fourth. The selection of a feeding-point at the extreme end of the line may be criticised ; but this point was chosen as a farther extension to Euston is under contemplation. The sub-station equipment is dealt with fully later.

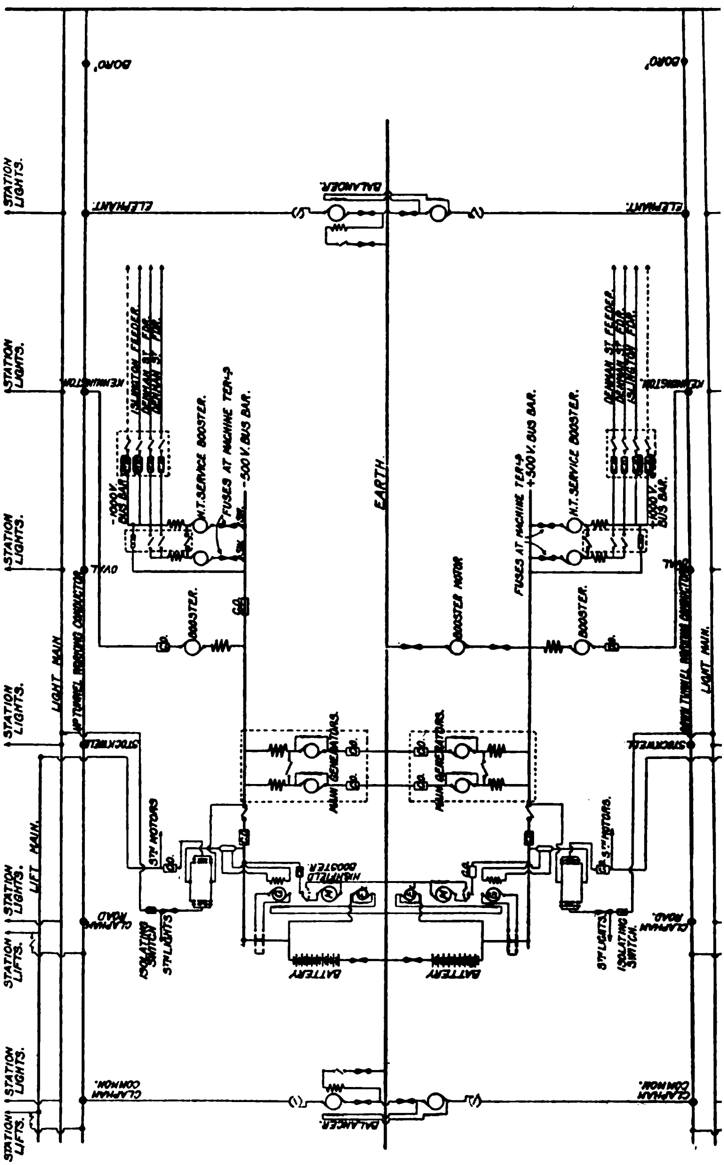
On the left-hand side of the main switchboard are arranged the generator panels, each machine having a separate panel. The 'bus-bars run along the entire length of the board. The top 'bus-bar being connected with the "up tunnel," the bottom with the "down tunnel," and the middle bar with the running rails. Either generator can be connected to the "up" or "down" side of the system, but the switches are interlocked so that it is impossible to connect any one


LONDON
BORO'
BORO DN STR
DOWN RD
SIDING.
UP RD
BORO' UP STAR
TUNNELS CROSS.
UP ROAD.
DOWN RD
ELEPHANT.
E.C. UP STR
E.C. DOWN STR
KENNINGTON.
K.O. UP FDRS UP STR
K.O. DOWN FDRS DOWN STR
OVAL.
OV. UP STR
OV. DOWN STR
STOCKWELL UP FDRS.
STOCKWELL
MOUTH OF UP TNL.
STOCKWELL DOWN FDRS ON SIGNAL CABIN
NEAR MOUTH OF SERVICE TNL.
LOOP
BIG RING
CLAPHAM RD.
UP STARTER.
DOWN STR
30'
DEAD END
LOCO PIT.
CLAPHAM COMMON.
BALANCER
SIDING.
ANGEL
DOWN BUS BAR.
ANGEL SUB STATION
UP BUS BAR.
LOCO PIT.
SIDING.
30'
CITY RD
C.R. UP STAR
C.R. DOWN STR
OLD ST
O.S. UP STAR
O.S. DOWN STR
SIDING
M.R. UP STARTER
SPARE LOCO.
MOORGATE.
BALANCER.
M.R. DOWN STR
UP ROAD
DOWN RD
TUNNELS RECROSS.
BK. UP STARTER.
BANK.
SIGNAL CABIN.
SPARE LOCO
BRIDGE.
L.O. DOWN FDRS. BORO SIDE OF SERVICE TNL.
L.O. UP FDRS. BANK SIDE OF SERVICE TNL.

machine with both "up" and "down" sides at one time. The Board of Trade panel, which contains the rail-drop recorder, leakage ammeter, and 'bus-bar voltage recorders, is placed between the generator and feeder panels. Each feeder panel contains the up and down feeders as in the case of the generator. The first feeder panel being that of the Stockwell feeder, both up and down contain an ammeter, automatic circuit breaker, and a knife switch, the latter being required as the circuit breaker does not entirely break the circuit, but, when a short-circuit occurs, throws in a resistance which limits the current to the maximum load for which the feeder is designed. This method of throwing in a resistance instead of breaking the circuit has many advantages. It saves the switch contacts, allows the switchboard attendant to see whether the "short" is removed before replacing the automatic circuit breaker, and also leaves the current on the working conductor, so that in most cases the locomotive is able to reach the next station at low voltage. The train lights are prevented from going out completely, which, from the passengers' point of view, is very important. All the circuit breakers, both generator and feeder, with the exception of the high-tension feeders, are similarly arranged. The Kennington feeder panel comes next on the right and, in addition to that already described, has a starting resistance for the booster and change-over switches, so that the feeders can be used with or without the booster as required. The following panel contains the starting and switching gear for the motor side of the motor-generators which are used for supplying current to the sub-stations. The last panel on this board contains an automatic circuit breaker without resistance, which separates the high- and low-tension switchboards in case of a heavy short-circuit. On the same panel switches are arranged so that the motor side of either motor-generator can be fed from both sides of the system as required. In the ordinary way it is usual for the generator supplying the "up" high-tension 'bus-bars to take current for its motor from the "down" low-tension 'bus-bars, and the "down" generators motor receives current from the "up" low-tension 'bus-bars. This arrangement is adopted to assist in balancing, but is sometimes convenient to feed both motors from the same side, should there be a large generator working on one side and a smaller one on the other.

In addition to using motor-generators for the high-tension service it is possible to use either of the 125 or 300 k.w. sets, and these can be used singly or in parallel. So that if the load is too heavy for the motor-generators, the 125-k.w. steam-set can be used in parallel with it. The first panel of the high-tension board contains the necessary paralleling switch-gear for the above purpose, and the next two panels contain the feeders for London Bridge and the Angel sub-stations respectively. All feeders are protected with automatic circuit breakers and main switches.

A separate board on the extreme left of the main board contains the switch-gear for the light- and lift-cables in connection with a battery on the Highfield system, and will be described later.


STATION LIGHTS.
STATION LIFTS.
LIGHT MAIN.
LIFT MAIN.
BORO'.
ELEPHANT.
KENNINGTON.
OVAL.
STOCKWELL.
CLAPHAM ROAD.
CLAPHAM COMMON.
BALANCER.
EARTH.
ISLINGTON FEEDER.
DENMAN ST. FDR.
DENMAN ST. FEEDER.
ISLINGTON FDR.
H.T. SERVICE BOOSTER.
FUSES AT MACHINE TER.
-500 V. BUS BAR.
+500 V. BUS BAR.
-1000 V. BUS BAR.
+1000 V. BUS BAR.
BOOSTER.
BOOSTER MOTOR.
UP TUNNEL BONDING CONDUCTOR.
DOWN TUNNEL BONDING CONDUCTOR.
MAIN GENERATORS.
STN. MOTORS.
HIGHFIELD BOOSTER.
BATTERY.
ISOLATING SWITCH.
STN. LIGHTS.

Cables Working Conductor and Rail Bonding.

All the cables with the exception of the Kennington feeders, which consist of the original Fowler-Waring cables, re-laid, are of the well-known Callender make.

The Stockwell feeders are two 0·32 square inch lead-sheathed and compounded cables in parallel for both "up" and "down" sides. The Kennington feeds, as already stated, are the old 0·32 square inch cables re-laid, two in parallel, for each side of the system. In the London Bridge sub-station four high-tension, lead-covered and armoured cables 0·35 sq. in. are used—two in each tunnel, or one cable for each reducer. The Angel sub-station feeders are similar to the above, but only two are at present installed, provision being made for a second set when required.

The diagrams Figs. 5, 6, 6A, and 6B of line connections show the method of dividing the working conductor into sections. At each station there is a switch fuse, and at Stockwell, Kennington, London Bridge, and the Angel, the feeders are connected to the working conductor through a double switch fuse. At the sidings additional switches are provided for breaking the working conductor into smaller sections, for repairs to carriages, etc. Diagram Fig. 6 gives the complete system of cables, etc. The working conductor itself is of channel steel of high conductivity. It has a cross-section of 4 square inches, and weighs 40 lbs. per yard. It is laid in 30-feet lengths, and is joined up with copper fish-plates, which also form the means of holding it down to the insulators. On the Islington extension the copper fish-plates were strengthened by steel plates on one side, as experience showed that the copper plates in some cases allowed the channel steel to get slightly out of truth. Under each joint or fish-plate there is a special holding-down insulator into which the copper fish-plates grip and hold the working conductor in position; the remaining insulators are simply let into the sleepers and serve as supports only for the working conductor. Fig. 7 shows the details of conductor and insulators.

Each running rail is bonded with two flexible bonds of 0·165 square inch section in bottom flange of the rail: see Fig. 8. In addition the rails are cross-bonded and joined to the tunnel at regular intervals. The up and down tracks are also cross-bonded at the cross-over roads.

In order to get from one side of the system to the other, or to change from the positive to the negative side, a wooden break 30 feet long is left in the working conductor. This length was chosen so that two locomotives coupled together could not make a thousand-volt "short." The locomotives run over these breaks by their own momentum, and as the collecting shoes are 13 ft. 9 in. apart, a break of 16 feet 3 inches is left. This break was found to cause an appreciable flicker in the train lights, and the difficulty was overcome by screwing metal plates on each side of the wooden strip and joining them up to the conductor by a fuse, leaving the actual break only 16 feet long. The drivers switch off the current on approaching the break, but if this precaution is neglected sometimes an arc is drawn out by the locomotive shoe, and the fuse blows before any harm is done (Fig. 9).

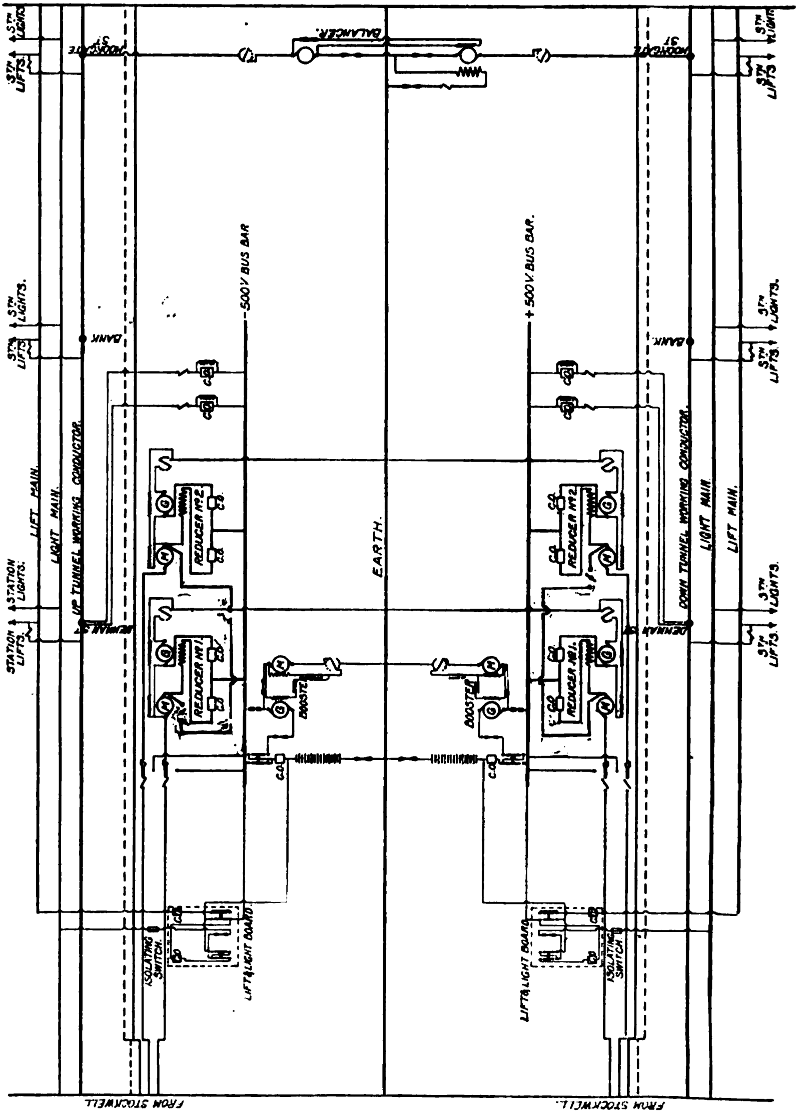


FIG. 6A.—Complete Diagram of System. London Bridge Sub-station Connections.

In addition to the feeder cables above described, there is a complete and independent set of cables for the supply of current to the electric lifts and also for the station lighting. The electric lifts on the Clapham extension are fed from an independent switchboard in the generating-station at Stockwell by two 0·25 square inch cables. The lifts between Stockwell and London Bridge being hydraulic, no cables are required. But from London Bridge to the Angel (both stations included) electric lifts are installed, and are fed from both sub-stations through special panels on the switchboards.

One special lighting feeder 0·15 square inch section runs the whole length of the line in each tunnel and supplies the station and signal lights. These cables are fed from the generating- and both sub-stations as follows :—

At the generating-station and the Angel sub-station the batteries in connection with the Highfield boosters have separate switchboards which are practically extensions of the 'bus-bars. The special light feeders are joined up to these boards through a fuse and thrown over switches, so that the lighting can be maintained from the 'bus-bars, the battery, or the battery working in connection with the boosters. The lift cables are similarly connected, but have an automatic circuit breaker instead of a fuse. At London Bridge sub-station ordinary non-reversible boosters are employed, and here the lighting and lift feeders are usually coupled up to the 'bus-bars, the former through a fuse and the latter through an automatic circuit breaker. Throw-over switches are also used to feed the lighting and lift system from this battery in case of necessity. As a further precaution at each station where electric lifts are installed, throw-over switches are fixed, so that, in the event of the special lift cables breaking down, the lifts can be fed direct from the working conductor.

Sub-Stations.

As already stated there are two sub-stations, one at London Bridge and the other at the Angel, Islington. The machine-room in the former is under the booking-hall floor, and the batteries are arranged in three arches, in two of which the cells are in two tiers, this arrangement being unavoidable on account of the amount of space available.

Each of the four high-tension feeders is connected to its own panel on the switchboard through an emergency quick-break switch operated by hand only. Connections are then made through the automatic circuit breakers and switches with the reducers and working conductor, as shown on the diagram, Fig. 6.

Four of the Electric Construction Company's continuous-current reducing motor-generators are installed at this sub-station. Fig. 10 shows a longitudinal elevation of the machines. The reducers are mechanically connected in pairs, one set working on the "up-" and the other on the "down-" side of the system. In this manner, in addition to these machines acting as reducing motor-generators, they also serve the function of balances. This effect can be plainly observed on the ammeters in the generator armature circuits. The current entering the motor or outside armature remains fairly steady, while that in the

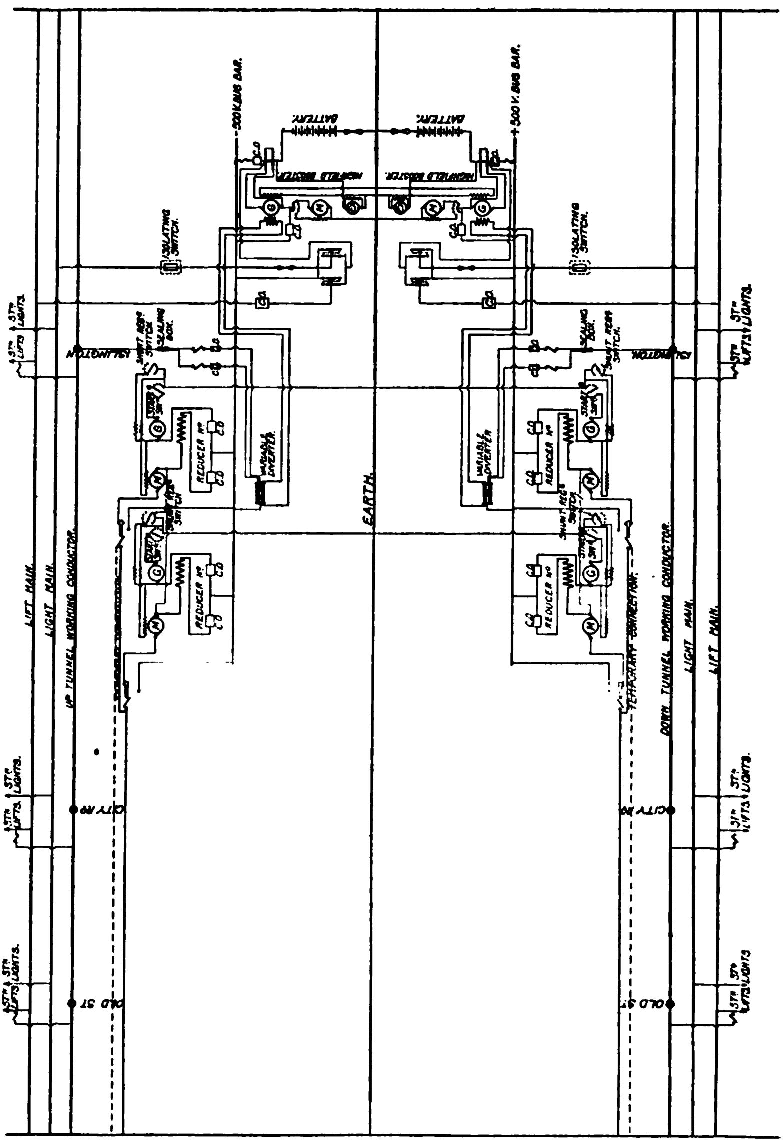


FIG. 6B.—Complete Diagram of System. Angel Sub-station Connections.

generator-armature varies considerably, showing that these armatures are also tending to maintain an electrical balance on the two sides of the system. It will be noticed that each machine has an auxiliary field- and series-winding in circuit with the feeder. This enables the machine to compensate for the variable feeder loss and to supply at all loads up to full normal load and overload current to the working conductor at the same voltage as the generating station 'bus-bars.

Each machine is capable of delivering to the working conductor 300 amperes at 500 volts continuously, the speed being about 600 revolutions per minute, and the overload, for considerable periods, being 400 amperes. Under ordinary full normal load conditions the armature current and voltage is as follows :—

Generator between working conductor and rails, 500 volts, 130 amperes.

Motor between high-tension feeder and working conductor, 430 volts, 170 amperes.

That is to say, compensation is provided for a line drop of 70 volts at 170 amperes.

The temperature-rise after six hours' run at normal full load does not exceed 70° F., and the machine can run for a further two hours on overload without excessive heating or sparking.

Tested as a transformer, the ratio of the output on the generator side to the input on the motor side is 91·5 per cent.

The battery contains 556 49 H.B. 11 type Tudor cells divided between the three arches, and so arranged that the cells between which there is a high difference of potential are placed in different arches. The following is the capacity of the cells :—

490	ampere hours	when discharging at	70	amperes	for 7	hours.
450	"	"	150	"	3	"
400	"	"	200	"	2	"
350	"	"	350	"	1	"

The cells are capable of standing a discharge of 500 amperes for short periods.

The 556 cells are, of course, divided up into two batteries, one on each side of the system. In each battery 32 cells are coupled up as regulators.

The boosters used in connection with the battery at this sub-station are of the ordinary E.C.C. non-reversible type. The motor side of each booster is shunt-wound, and capable of working at any E.M.F. between 480 and 510 volts. The generator side delivers up to 150 amperes at 200 volts. The machines run at 600 revolutions per minute, and have a commercial efficiency of 85 per cent. at full load. The battery is usually charged during the periods of light load or other times convenient to the generating-station. It is practically kept in reserve as regards supplying current to the working conductor, but is used to supply the light and lift cables, and for lighting at night when all the generating plant is shut down. When used on the 'bus-bars to supply current to the working conductor, the regulating cells are brought into use, the 'bus-bar voltage being too steady to allow the battery to charge or discharge on the line. It will, of course, take

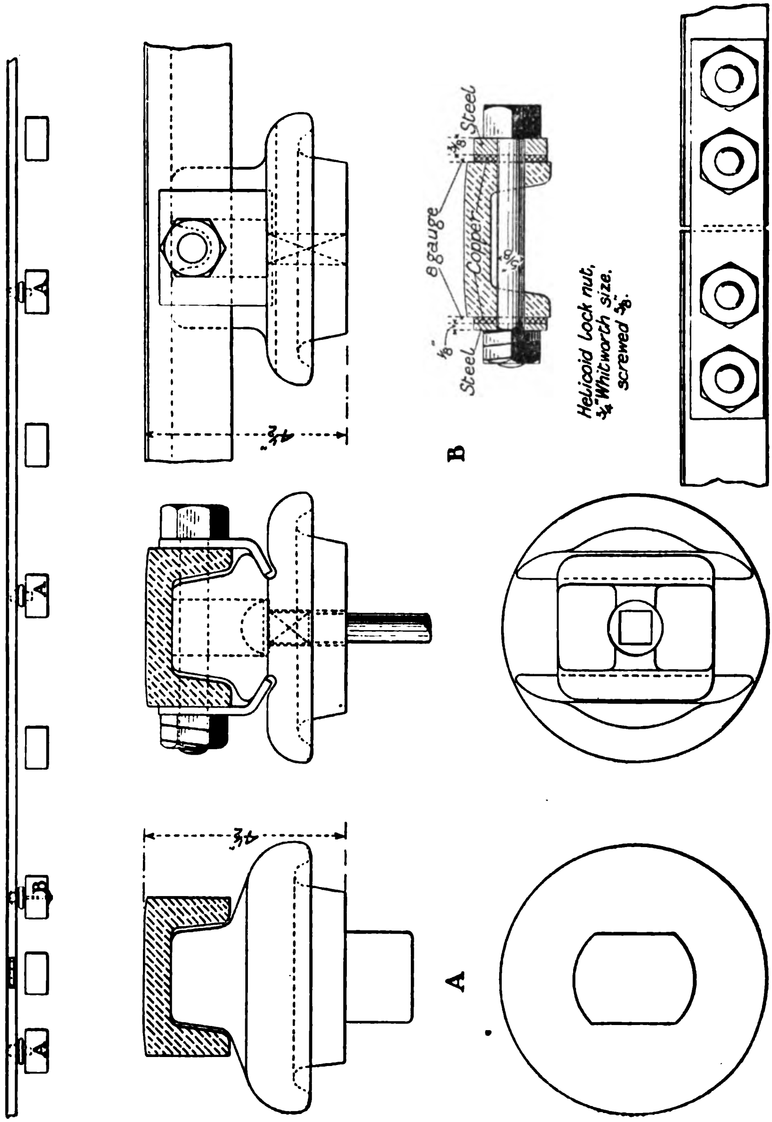


FIG. 7.—Details of Working Conductor and Insulators.

heavy peaks under these conditions, but then the voltage drop must be perceptible. The behaviour of the battery at this and the Angel sub-stations shows in a marked degree the advantage of a reversible booster.

The Angel sub-station differs slightly from that just described, the whole of the machinery and battery being placed under the station platform and a piece of the service tunnel.

The reducers are exact duplicates of those at London Bridge, with

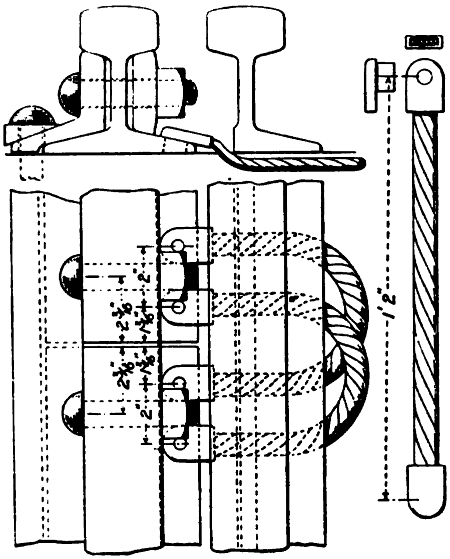


FIG. 8.—Rail-bonding.

the field-winding slightly altered to compensate for the higher cable loss. Although two complete lines (or sets) of reducers are at present installed, together with the necessary switch-gear, only one set of cables is run from Stockwell, one set of reducers being able to do the

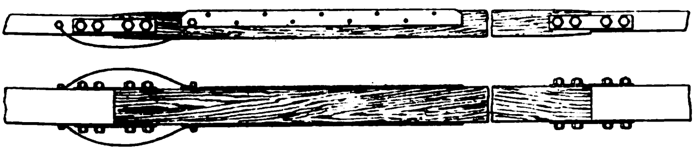


FIG. 9.—Cross-over Break in Working Conductor.

work at full load. Provision has, however, been made for a second set of cables when required for the contemplated extension of the railway to Euston. Either set of reducers can be run as desired. The essential difference between this sub-station and that at London Bridge lies in the method of using the batteries. Here instead of the ordinary non-reversible boosters, the Highfield system is used, with the result that the batteries are always on the line either discharging or charging.

As the Highfield system has already received exhaustive treatment before this Institution at the hands of the inventor, it is unnecessary to go into details beyond giving the size of the particular plant in operation. Each booster (one each for the "up" and "down") consists of a motor, generator, and exciter opposer, all coupled direct to one shaft, the rated capacity of the booster being 420 amperes, with a boost of 150 volts. The machines are capable of taking an overload of 50 per cent. for half an hour, and of 100 per cent. overload for momentary peaks. The diagram Fig. 6B shows the connections of the Highfield system as employed at Islington, and the arrangement of coupling up the light and lift cables.

The switchboard is similar to that at London Bridge, with the exception of the Highfield panels. The battery consists of 500 Tudor 210 H.B. 15 cells of the following capacity :—

588	ampere hours when discharging at	84	amperes for	7	hours.
540	,, ,,	180	,,	3	,,
480	,, ,,	240	,,	2	,,
420	,, ,,	420	,,	1	,,

with a maximum discharge rate of 600 amperes for short periods.

At both sub-stations arrangements are made on the switchboards so that the high-tension cables can be coupled to the 'bus-bars direct, and feed in as low-tension feeders in case an accident should occur to the high-tension plant.

Generating-Station Battery.

As already mentioned, there is a battery at Stockwell in connection with the Highfield boosters. The battery consists of 500 chloride 11 cells of the following capacity :—

245	ampere-hours when discharging at	35	amperes for	7	hours.
225	,, ,,	75	,,	3	,,
200	,, ,,	100	,,	2	,,
175	,, ,,	175	,,	1	,,

with a maximum discharge of 250 amperes for short periods.

The boosters are similar to those at the Angel sub-station, and have a rated capacity of 175 amperes with a boost of 150 volts.

The battery at the generating-station may appear to be very small, but it is only used in connection with the supply of current to the lifts on the Clapham extension and the lighting circuit in parallel with the other sub-station batteries.

Milking transformers are installed at the generating- and sub-stations with leads arranged round the battery rooms, so that any backward cell can be milked and brought up to its proper voltage and specific gravity without affecting the other cells. These transformers simply consist of a small 500-volt motor driving a generator giving about a maximum of six volts and a current corresponding to the rated charge for each battery. Suitable switchboards are provided, so that the transformer can be used on either side of the system.

Lifts.

The travelling public, as a rule, are not inclined to look upon the lifts as a very important factor in the working of a deep-level railway until, perhaps, they have to walk up the stairs, and then they highly appreciate their value. Nevertheless, the question of carrying the passengers vertically is quite as important as their carriage horizontally, and the costs are considerably more per ton-mile or passenger-mile.

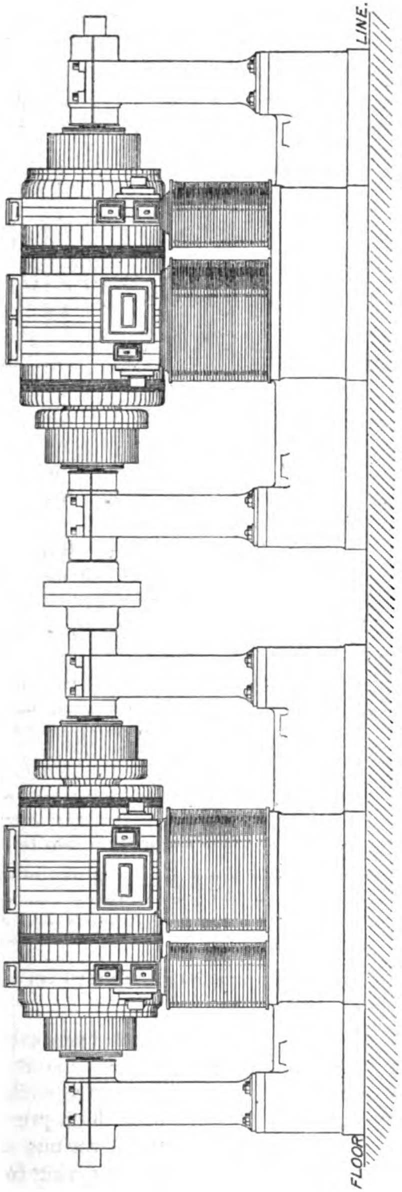


Fig. 10.—Reducing Transformer.

Hydraulic Lifts.

As mentioned earlier in the paper, the lifts on the railway from Stockwell to King William Street are hydraulic, the high-pressure water being supplied from the generating-station at Stockwell. The pumping plant consists of three compound engines with cylinders 17 and 29¾ inches, and 20 inches stroke. The piston-rod of each cylinder projects through the back cover, and to this the pump plunger is attached. Steam is now supplied to these engines through a reducing valve, from the same range of boilers as supplies the main engines, the stop-valve pressure being 100 lbs. per square inch.

The maximum speed of the engines is 100 revolutions per minute, and this is controlled by an ordinary governor acting on a throttle valve, the governor only coming into operation in case an accident occurs, such as the bursting of a pipe. Under ordinary working conditions the speed is controlled by a throttle valve in the main steam

pipe common to the three engines. This valve is operated by a chain from the accumulator, which shuts off steam when it reaches the top of its travel, and opens the valve again after it has descended a few feet. In this manner the engines are very often standing, and the speed varies from rest to 100 revolutions per minute, the average speed taken during one day's working being 24 revolutions per minute. The working pressure at the pumps is 1,240 lbs. per square inch, which can be varied by the weight of the accumulator. Alongside the engines are

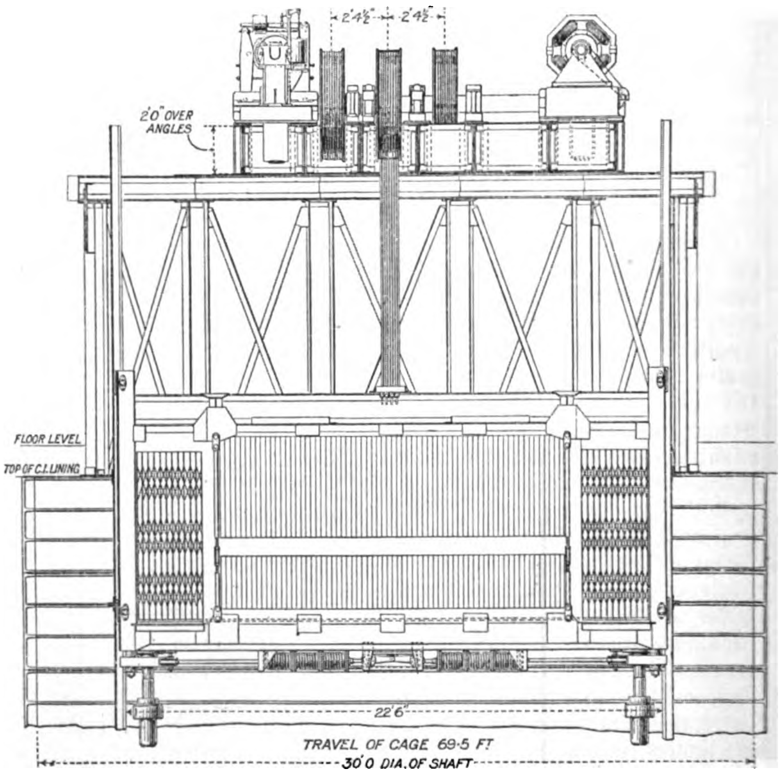
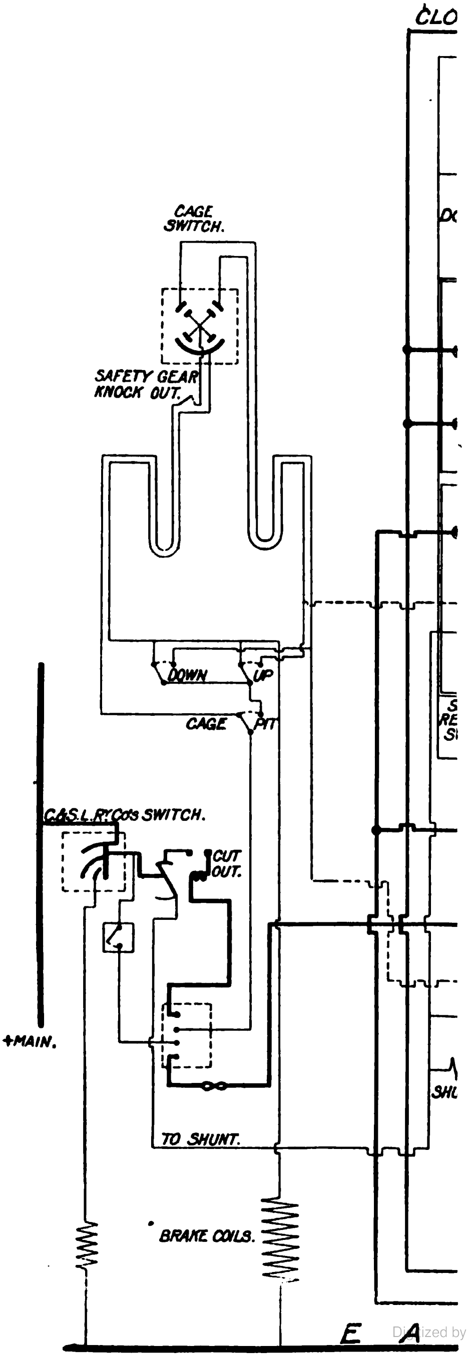


FIG. 11.—General Arrangement of Electric Lift and Gear.

two accumulators. The second was erected some time after the plant was installed, and has a greater capacity than the original accumulator. The diameters of the rams are 14 inches and 18 inches respectively, with a travel of 17 feet. The high-pressure water is conveyed in cast-iron pipes to the lifts at the various stations. The diameter of this pipe at Stockwell is 9 inches, tapering to 4 inches between the Borough and King William Street stations. The water, after being used at the stations, is returned to Stockwell by a system of cast-iron pipes tapering in the same ratio as the high-pressure mains, to be pumped and used


CLO
CAGE SWITCH.
SAFETY GEAR KNOCK OUT.
DOWN
UP
CAGE
PIT
C.&S.L.R'Y.Co's SWITCH.
CUT OUT.
+MAIN.
TO SHUNT.
BRAKE COILS.
SHU
E
A

over again. At each of the six stations are two lifts, the capacity of each being 50 persons. The average travel is about 50 feet.

Kennington station has now only one hydraulic lift, the second one being operated electrically. The lifts are not direct-acting, the ram being placed at the side and the cage suspended from six steel wire ropes, two of which are attached to the counter-balance weights, and the remaining four to the crosshead of the ram through a system of pulleys having a 3 to 1 ratio, *i.e.*, the travel of the cage is three times that of the ram. The method of control consists of a hand rope in the cage which operates a valve, allowing the water to enter the cylinder as the lift ascends, and to leave as it descends. The hydraulic plant (with the exception of the second accumulator at Stockwell made by Messrs. Eastons) was manufactured and erected by Messrs. Armstrong & Mitchell, of Newcastle-upon-Tyne (now Armstrong, Whitworth & Co.).[1] It should be mentioned that there is an accumulator at the Elephant and Castle station to steady the pressure ; the diameter of the ram is 11¾ inches and the travel 17 feet.

Hydraulic capstans are fitted in the depôt for shunting purposes, and these, together with motor lifts in the repair shops, are operated from the same supply.

Electric Lifts.

The lifts on the northern and southern extension are electric and, with the converted lift at Kennington, number 26. The cages for these lifts are very similar to those used in connection with the hydraulic lifts, and have approximately the same capacity.

The whole of the twenty-five electrical lifts on the extensions were manufactured and erected by Messrs. Eastons, of Erith, and, with the exception of the position and size of the motor and winding gear, are similar. In the case of the Clapham and Moorgate extensions, the motor and winding gear is fixed at the bottom of the lift shaft, and in the case of the Islington extension at the top. This latter arrangement is very much more suitable and convenient.

Briefly described, the machinery consists of a compound-wound four-pole motor, on the extended shaft of which is secured a mild-steel, case-hardened worm, geared to a worm wheel having a phosphor bronze rim, with cut teeth, shrunk and keyed to a centre. The shaft of this carries the rope-driving sheave. The eight steel wire ropes passing over this sheave are given additional contact by a similar sheave running light and quite close to the driver; the ropes going over and under these two sheaves form a figure like the letter S, which gives an excellent grip, but is more or less objectionable from the point of view of rope renewals.

The cage is suspended from one end of the ropes, and the balance

[1] Each lift is fitted with safety gear which comes into action should the tension on the ropes decrease beyond a certain point. A broken or loose rope would have the same effect. The safety gear proper consists of a number of cams fixed to the top and bottom of the cage, and, when brought into action as explained above, these cams grip the lift guides and hold the cage in position.

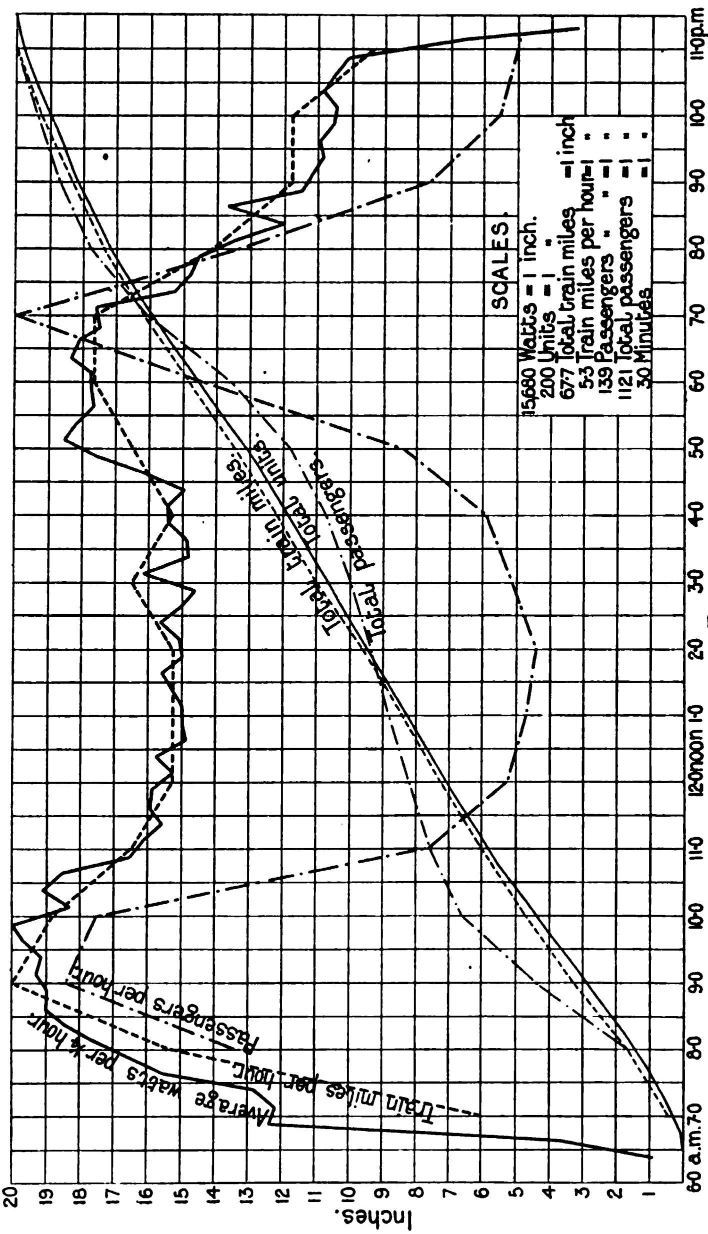


FIG. 13.—Record of All-day Test, January 18, 1894.

weights from the other. The balance weights are arranged to balance the weight of the cage and about half the load, this being generally the most economical working arrangement. At stations, however, where the traffic is light, a slightly smaller balance weight proves more economical. Safety arrangements are provided to grip the lift guides somewhat as in the case of the hydraulic lifts. The act of bringing the safety gear into action also cuts off the current from the motor. Fig. 11 shows the general arrangement of lifts and gear.

The results of working show that the electric lift has many advantages over the hydraulic lift, but in the case, at any rate, of the large lifts, the control of the hydraulic lifts is very much more satisfactory than the electric, both from the point of view of operation and upkeep.

The operation of one simple valve by a hand rope in the cage gives perfect control of the hydraulic lift under all conditions, and with a reasonable amount of care the starting and stopping is perfect, while the speed can be anything desired within reasonable limits. The following description of the control for electric lifts shows how much more complicated and costly is the electric lift on this score; but before going into the details of the existing controlling arrangements, it may be interesting to give a short sketch of the development of this arrangement. The railway company's liftmen being used to pulling a rope to start or stop a lift, it naturally appeared that this was the line to be followed for the electric lifts, and this method having proved very satisfactory in the case of small electric lifts for offices. When applied to large lifts to carry 50 or more persons, the case presented many difficulties. In small office lifts the hand rope simply operates a rheostat switch which starts the motor with a resistance in the circuit, and gradually cuts out resistance as the motor gains speed.* The rate at which this resistance is cut out depends upon the manner in which the attendant pulls the rope. With an office lift the switch contacts are arranged in a circle with a diameter of about 12 or 14 inches and the movable contact presents no difficulty on the score of friction, and the travel of the hand rope can be made short.

In the earlier days, when converting the hydraulic lift at Kennington to electric working, the simple hand-rope method as used in office lifts was tried, but was found quite unsuitable for the new conditions. Here the same kind of circular rheostat switch was adopted, but of much larger dimensions, the diameter of the contact circle being 30 inches. The hand rope had to go over a number of guide pulleys, and to allow of a reasonable pull on the rope the travel had to be made much longer than in the case of the hydraulic lift. This alone called for far more judgment on the part of the attendant. Having cut out sufficient resistance to allow the motor to start, the next pull at the rope when the lift was in motion caused a jerk if the pull was too vigorous, or part of the resistance might be left in circuit all the time, thus decreasing the speed of the motor. Again, too sharp a pull at starting caused a

* The action of switching on the current at the same time released the brakes on the worm shaft, and when the current was switched off the brakes were applied.

jerk as the lift began to move. In coming to the end of the travel the resistance had to be put in circuit again, and here the amount of judgment required caused the lift very often to stop short of the floor or to overrun it. Rubber and spring buffers were tried to make the lift stop exactly, but were found to cause violent jerks unless the attendant allowed the lift to strike them very gently, and to do this he had to cut off the current exactly at the right time, which did away with the necessity for buffers except in the case of emergency, in which case a considerable margin of travel above or below the floor had to be allowed. The limit switches, which originally cut off the current entirely if the lift should travel, say, 18 inches too far, were then set to come into operation at the completion of each journey. In this manner the attendant had only to start the lift with the hand rope, and upon reaching the end of the travel the cage itself cut off the current and applied the brake. As a lift has sometimes to carry its maximum load and perhaps the next trip has only a few passengers, it will be seen that the position at which the lift cage in the shaft operated the main break switch varied for different loads if the exact stopping positions were maintained, and of course this in practice is an impossible adjustment. If the position was set for an average load, a full load coming down, on account of the additional momentum, would cause the lift to go below the floor, and with an entirely empty cage the reverse would happen, the same reasoning, of course, applying to the up-stroke. This difficulty is overcome in the case of hydraulic lifts by the ram and cylinder forming a sort of buffer, and after a considerable number of experiments hydraulic buffers were applied to the bottom of the cage and balance weights, and these gave satisfactory results.

In the construction of the electric lifts for the Moorgate and Clapham extension the experience gained in controlling arrangements at Kennington was used in the gear for the new lifts. The size of the switches was increased, and in the case of the large lifts at the Bank station, the rheostat switch was about 4 feet in diameter. Considerable trouble was experienced, especially in the matter of control, when the new lifts were started. In fact they did not work nearly as well as the converted lift at Kennington; the starting and stopping was not as good, and this in a great measure, the author thinks, was due to the difference in the arrangement of balance weight, coupled with the use of the larger starting switches. At Kennington the balance weights, which were equivalent to the cage weights, were attached to separate ropes, and did not travel over the driving sheaves, and this arrangement seems to have given more flexibility to the system. Arrangements were next made to short-circuit the armature through a resistance, so that it should help as a brake, and the result was a decided improvement in helping to stop the lift gradually at the end of its travel. This form of controlling gear with the short-circuiting of the motor-armature proved to be a step in the right direction, but the objectionable long-pull hand rope still remained. Experiments were then made with a small motor driving the rheostat switch, the motor being controlled from the cage; the result was an improvement on the hand-rope arrangement, but still had several defects. Experiments were continued with an arrangement of solenoids. The

system shown in Fig. 12 was the result, and is now fitted to all the electric lifts.

In a few words, this controlling gear consists of three sets of switches operated by solenoids. One set closes the motor circuit for the up journey, the other for the down journey, and the third cuts out a starting resistance in the armature circuit. The exciting current for the up and down switches is controlled from a small switch in the lift cage. In order that the working of this gear may be understood, the following detailed description is given.

The gear consists of three sets of switches, each worked by a solenoid or long-stroke magnet, as shown in the drawing Fig. 12. One set, A, closes the motor circuit for the down journey, and the other, B, closes the circuit for the up journey, whilst the third, C, cuts out the resistance in the armature circuit. All the switches are shown in their bottom positions. When the solenoids are excited they lift the switches to the top position, and when the current is cut off, the switches and solenoids are brought to the bottom position by their own weight. The closing switch A consists of a solenoid which works a vertical spindle, on which is mounted a "closing switch," a "short-circuit switch," a "solenoid-making switch," and a "shunt-reducing switch." When the solenoid is excited and the spindle and switches pulled up, the "closing switch" makes contact between 1 and 2, the "short-circuit switch" between 5 and 6, the "solenoid-making switch" between 7 and 8, and the "shunt-reducing switch" between 11 and 12 respectively. When the solenoid is at its bottom position, the "closing switch" makes contact between 3 and 4, and the "solenoid-making switch" between 9 and 10 respectively. In addition to these switches there is a "breaking switch" with a contact 24 fixed on the top of the solenoid, which makes contact with 23 when the solenoid is up. 23 and 24 are placed between the two poles of a "blow-out magnet," 24 is connected to contact 1 through a flexible cable, and 23 is connected to contact 3, so that when the solenoid A is excited and pulled up there is a connection between 1 and 2 through 24 and 23, in addition to the connection through the "closing switch." The contact 24 is arranged so that it can slide in its support, and is pressed against 23 by means of a spring, which is so adjusted that 24 and 23 remain in contact for a short time after the "closing switch" has left 1 and 2. When the connection between 1 and 2 through the "closing switch" is broken, the current between these two contacts passes through 24 and 23, and as the cable is wound round the "blow-out magnet" this magnet becomes excited, and creates a strong field between the points of the magnet where the contact between 24 and 23 is made. When the solenoid A has moved downwards a little further, the connection between the contacts 1 and 2 is broken between contacts 24 and 23, an arc is formed between these contacts, and this arc is instantly disrupted by the magnetic field between the points of the "blow-out magnet." Exactly the same action takes place in closing switch B, which is similar to closing switch A, with the exception that it has not got a "short-circuit switch" and contacts similar to 5 and 6 on closing switch A. Contacts 5 and 6 are connected through a "short-circuit resistance," and are placed in

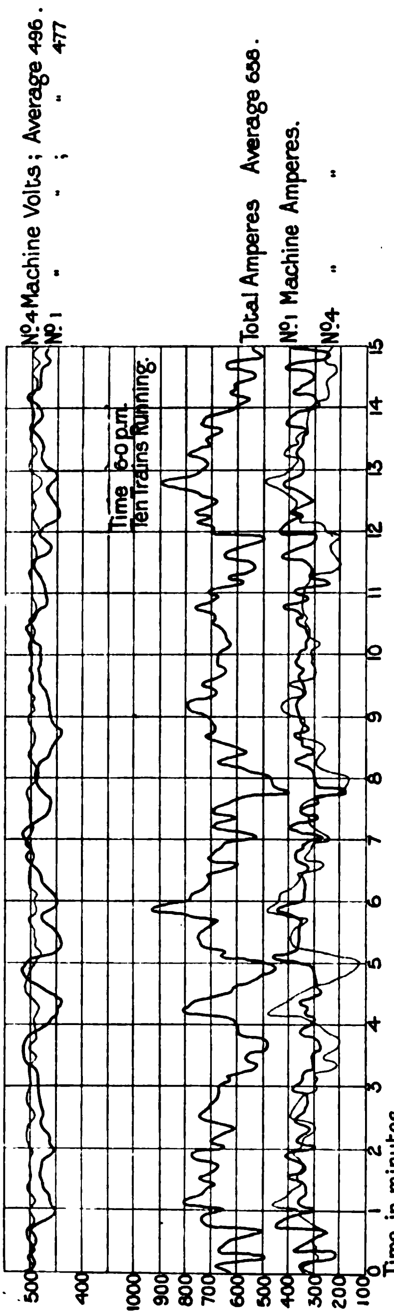


FIG. 14.—Volt- and Ampere-Curves, All-day Test, January 18, 1894.

the armature circuit. When the solenoid A is pulled up, the "short-circuit switch" short-circuits this resistance so that the current passes direct between 5 and 6 through the switch, and when the solenoid is down the current between 5 and 6 has to pass through the "short-circuit resistance."

The "shunt-reducing switches," which are placed in the shunt circuit, are arranged to work in the same manner as the "short-circuit switch," viz.: When their respective solenoids are up, the switches connect the contacts 11 and 12 or 21 and 22 respectively, so that the shunt current passes direct through the switch instead of going through the "shunt resistance." When the solenoids are down, and the motor at rest, the shunt current has to pass through the shunt resistance, and the current passing through the shunt circuit is thereby greatly reduced, and the temperature of the field coils kept down.

The "rheostat switch" consists of a solenoid C, which works an oscillating lever fixed on a pivot, and on the end of this lever is mounted a switch, which moves over a series of contacts which are connected with the "shorting resistance." This switch connects these contacts with a plate 29 mounted on pillars directly above the resistance contacts. The rubbing faces of the switch are pressed against the plate and the resistance contacts by means of springs, arranged so that the pressures are always balanced.

To prevent the solenoid pulling the lever too quickly, it is connected with a "dash pot" with an adjustable bye-pass, so that the time taken in cutting out the resistance may be adjusted as desired to prevent shock at starting. To enable the switch lever to get quickly back into its bottom position, the piston in the "dash pot" is fitted with a valve which will allow the oil to pass quickly from one side of the piston to the other. This valve remains closed by the pressure when the lever is being pulled up by the solenoid.

The "solenoid-making switches" are arranged to protect the controlling gear and motor from short-circuits should the solenoids stick in their up-positions or should the attendant in the cage try to reverse too quickly. The circuit to the solenoids A and B cannot be closed unless the solenoid C is down, as the current has to pass through contacts 27 and 28, and these contacts are not connected, except when the solenoid C is near its bottom position.

In addition to this, the circuit to solenoid A cannot be closed unless solenoid B is down and its "solenoid-making switch" is connecting contacts 19 and 20. Further, the circuit to solenoid B cannot be closed unless solenoid A is down and its "solenoid-closing switch" is connecting contacts 9 and 10.

The "solenoid-reducing switch" is fixed on the rheostat switch, and is arranged so that the current passing from solenoid C to the return main has to pass through the contacts 31 and 32. When the solenoid C is near the top of its stroke a tappet upon it strikes the lever on which contact 31 is fixed, so that this contact leaves 32 and the current from solenoid C has to pass through the "current-reducing resistance." The contacts 31 and 32 are placed between the poles of a blow-out magnet similar to those on the "closing switches," and the arc which

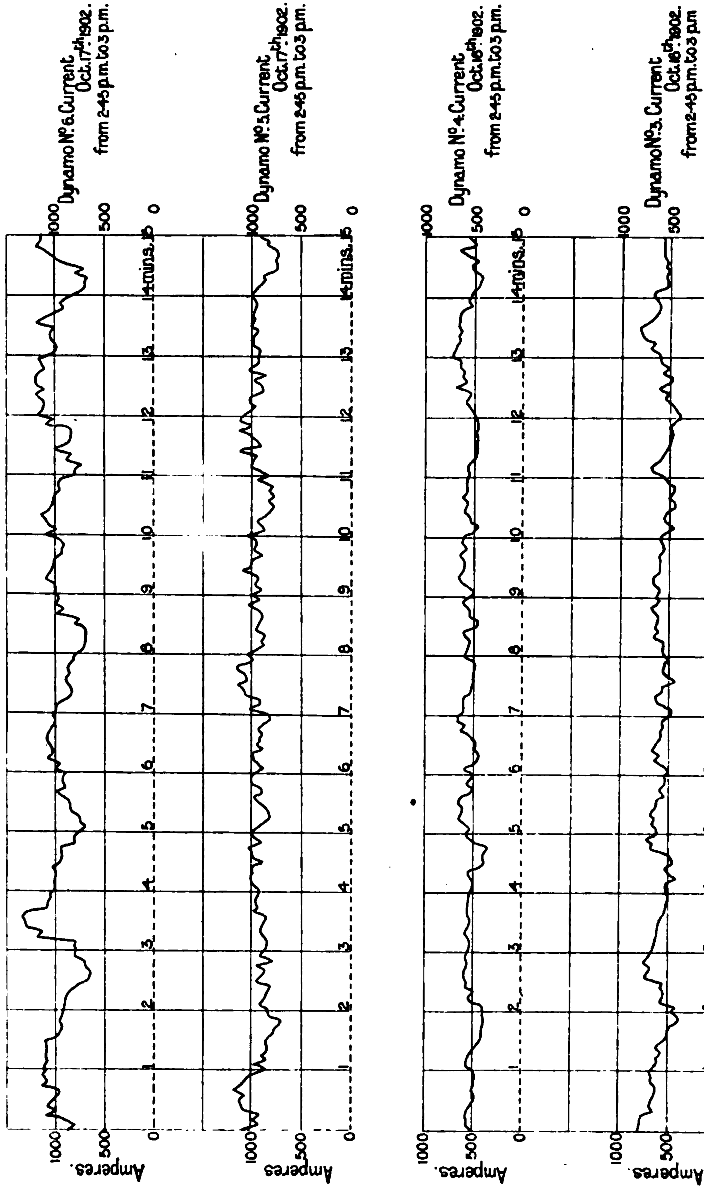


FIG. 15.—Load-Variation on Corliss and Willans Engines.

forms between 31 and 32 is disrupted at once if the circuit is broken. By means of this switch the working current in the solenoid circuit is, when the solenoids are up, reduced to that which is required to hold them in position. The solenoids are worked from two controlling switches (connected in parallel) in the cage. When the handle of one of these switches is moved to the "up" direction the circuit to solenoids B and C is closed, and when the lever is moved in the "down" direction the circuit to solenoids A and C is closed.

In addition to the contacts for the solenoids these switches are also fitted with contacts for the magnetic brake circuit, and these contacts are arranged so that the brake circuit is closed before and broken after the solenoid circuit, so that the brake may be released before the solenoids are lifted and the current put on the motor and that the brake may be kept off after the motor circuit is broken. When the lever of the controlling switch is moved from mid position towards "up" position, the brake circuit is first made and the brake releases its grip on the brake pulley. The solenoid circuit is next made and the current passes first through contacts 9 and 10, round solenoid B, through 27 and 28, round solenoid C, and then through 31 and 32 to the return main. Soon after solenoid C begins to move the connection between 27 and 28 is broken, but before this happens solenoid B is at its top position and the "solenoid-making switch" has connected 17 and 18, which are in parallel with 27 and 28, and through which the current passes to solenoid C. When solenoid "C" is up, the contact between 31 and 32 is broken, so that the current passes from the solenoid through the "current-reducing resistance" to the return. When the lever of the controlling switch is moved from mid position towards "down" position, a similar cycle as described above takes place with the exception that the current passes first through contacts 19 and 20 to solenoid A and then to contacts 27 and 28. When the solenoid B is up, the main current from the positive main passes through 13 and 14 to the armature of the motor, then through 3, 4, and 5 through the series-turns on the motor field to the last contact 30, on the "rheostat switch," through the "starting resistance" on to the plate 29 and then to the return main. When the rheostat switch lever is at its top position and all the starting resistance is cut out, the switch makes a direct connection between 30 and 29. When the solenoid circuit is broken, the solenoids drop to their bottom position, the armature becomes short-circuited and generates current flowing in the opposite direction through 16 and 15, through the "short-circuit resistances," 5, 4, and 3, and back to the armature. By adjusting the "short-circuit resistance" the armature can be made to pull up quickly or slowly as required. The short-circuit is also connected to the return main through the series-turns on the motor and the starting resistance. When the solenoid A is up, the main current passes through 1 and 2 to the armature, then through 16, 15, 6 and 5, through the series-turns on the motor and the starting resistance as described above. When the solenoid circuit is broken, and the solenoid A has dropped to its bottom position, the current generated in the armature passes through 3, 4, and 5, through the "short-circuit resistance" and through 15 and 16 back to the armature.

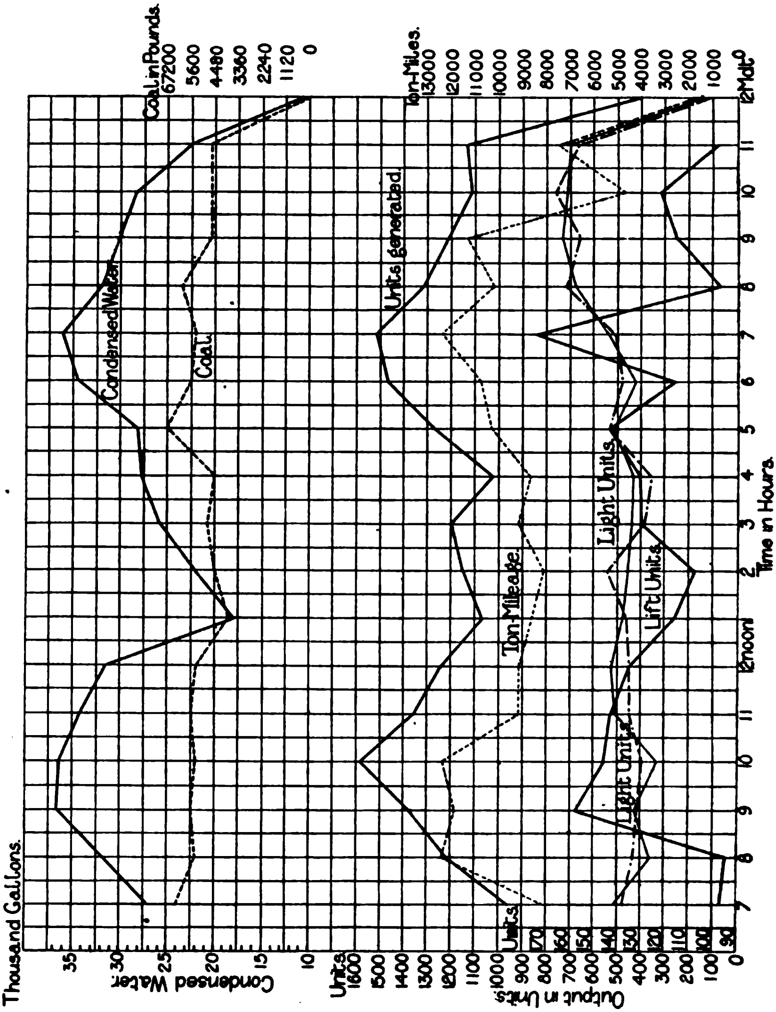


FIG. 16.—Record of All-day Test, April 8, 1903.

In addition to the controlling gear and its switches, the following switches are fitted :—

Main switch which, when broken, disconnects the whole system from the positive main. This switch is fitted with an extra contact connected to the return main through a resistance, so that when the connections to the main are broken the shunt becomes short-circuited through this resistance;

Automatic overload cut-out;

Emergency switch arranged to break the circuit if the cage should accidentally overrun the top and bottom floor levels;

Fuse in main circuit;

Fuse in shunt circuit;

Main switch for controlling-gear circuit;

Fuse in controlling-gear circuit;

Knock-out switch in controlling-gear circuit which breaks the circuit and stops the motor should the safety gear on cage come into action.

The controlling switches in the cage are arranged to act as limit switches, as the switch arms are brought back into the mid position by levers fitted to the back of the switches striking against blocks fixed in the lift shaft at the top and bottom levels.

WORKING RESULTS AND TESTS.

Before going into the results of working obtained on the present line it may be interesting to give the result of an all-day test made in January, 1894. The coal was weighed and the water measured from starting in the morning at 6 a.m. until the generating-station shut down at 11.30 p.m. During the test six Lancashire boilers and two of the Fowler engines were at work. The hydraulic engines operating the lifts were fed with steam from the same boilers, and the amount of coal used for these pumping engines was determined by a previous test which gave six tons per day.

The electrical output of the station was 4,005 units. The following table gives the whole of the results of the day's working. It will no doubt be noticed that the coal and water per unit generated are very high, especially the water, but this is accounted for by the fact that the engines were only running with anything like full load for about 5 hours out of the 17·5 hours of the test. The difference between the units per ton-mile at the switchboard and on the locomotive will probably also appear striking, but in this difference is included the current used in shunting the trains into and out of sidings and also the transmission losses. The units per ton-mile on board the locomotive were observed when driven under the best conditions, and it is probable that in ordinary working the driver did not take such care in driving. The transmission losses as measured between the switchboard and locomotive were 10·5 per cent. The diagram Fig. 13 shows the results plotted.

The diagram Fig. 14 gives the generating output with 10 three-coach trains running. The voltage curves show that there was a maximum

variation of 80 volts at the generating-station, and a comparison with the present switchboard voltage curve is interesting and needs no further comment.

All Day Test, January 18th, 1894.

Total coal, 24 tons = 53,800 lbs., North-country small.
Total coal used for generating-station, 18 tons = 40,400 lbs.
Total water, 371,400 lbs.
Pounds of water per pound of coal = 6·9 (water at about 60° F.).

Units generated	4,005	
Pounds of coal per unit	9·95	
„ „ water „ „	69·2	
Train-miles	1,354	
Ton-miles	46,800	
Train locomotive and station lighting	778 units	
Units per ton-mile at switchboard ...	·069	Including shunting operations at termini and siding, distribution losses, etc.
„ „ „ on locomotive ...	·0515	Average speed 13·62 m.p.h.
Coal per ton-mile at switchboard ...	·686 lb.	
„ „ „ on locomotive ...	·512 „	

Slow-Speed *v.* High-Speed Engines.

Having two widely different types of engines which at certain times do practically the same amount of work, it will no doubt be interesting to give the results as to their working.

As mentioned earlier, the Willans engines came well up to their guaranteed steam consumption on the test held at Rugby, and the comparison of working results refers to the 300-k.w. Willans and the 800-k.w. Corliss sets. The results of the guarantee tests are first given.

On test, the 300-k.w. Willans set when giving 559·31 I.H.P., that is the normal load, the steam consumption was 17·73 lbs. of steam per B.H.P., the efficiency of the generator being 93 per cent., the steam per kilowatt-hour comes out at 25·5 lbs. In a similar manner the steam consumption on overload, or when the engine was indicating 676, was 23·1 lbs. per kilowatt-hour. The pressures in the steam chest during the tests were 145 and 143 lbs. per square inch, and the vacuum 23·2 and 23·3 inches of mercury respectively.

The 600 to 800 k.w. Corliss set was tested after erection at Stockwell on an artificial load, the water from the condenser being measured in two tanks which were previously filled with water to the marks used in the test and weighed. The first test on this set was for ten hours at normal load, or 977·25 I.H.P., followed by an overload test for one hour when the mean indicated horse power was 1,173. The dryness of the steam was tested by a Carpenter's calorimeter placed between the engine stop valve and the high-pressure cylinder, the mean of six readings showing 4·5 per cent. of moisture. The vacuum was fairly steady at 25·75 inches of mercury. The result of the normal load test

was a steam consumption 21·57 lbs. of steam per kilowatt-hour, and the overload test 22·5 lbs. of steam per kilowatt-hour. The makers, however, point out that if allowances were made for the moisture in the steam the result would be 20·4 lbs. of steam per kilowatt-hour for normal load. During the overload test the steam pressure dropped to 132 lbs. per square inch, which was claimed as equivalent to 0·35 lb. of steam per I.H.P. against the engine. If this allowance, together with moisture in the steam, is made, the steam consumption per kilowatt-hour comes out at 20·93 lbs.

Before, and shortly after, the opening of the Clapham extension, the load was such that the two 300-k.w. sets were able to deal with it, and in order not to have the Corliss sets standing and to give the Willans sets a rest, the Corliss sets were frequently run on alternate days, the maximum load never exceeding that which could be easily taken up by

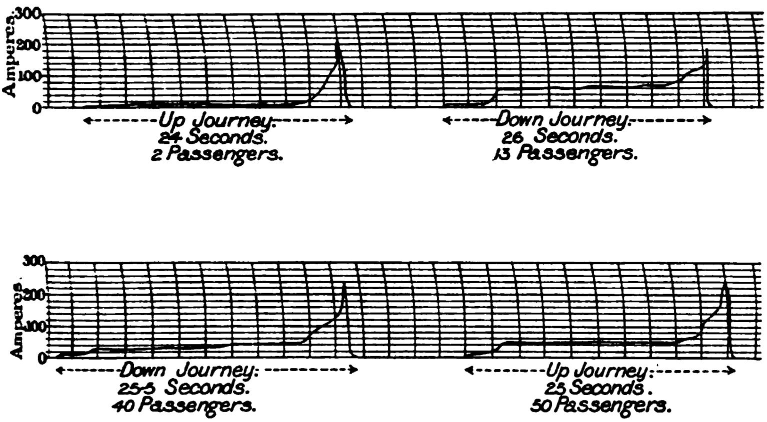


FIG. 17.—Recording Ammeter Curves. Lift-Diagram.

the 300-k.w. sets. After a short period of running under these conditions, the stokers said it was easier to keep up steam when the Corliss sets were running. The author at first looked upon these remarks as a fad on the part of the stokers, but the latter adhered to their statement, and so the condensed water was measured and the units generated taken during certain periods of the day, with the result that the steam per k.w.-hour for the 300-k.w. sets was 32 lbs. and 26 lbs. for the 800-k.w. sets. In October, 1902, tests were again made, under ordinary everyday working conditions, during the periods of light load, that is from 12 noon to 3 p.m.

The conditions of the later tests were not, however, exactly similar to those of the earlier tests, as it was necessary to run the two 125-k.w. sets in addition to the two 300-k.w. sets, the load during the test being too heavy for the latter alone.

The measured condensed water in each case included that used in driving the air and circulating pumps for the condensing plant, and may therefore be taken as constant. The condensed water was

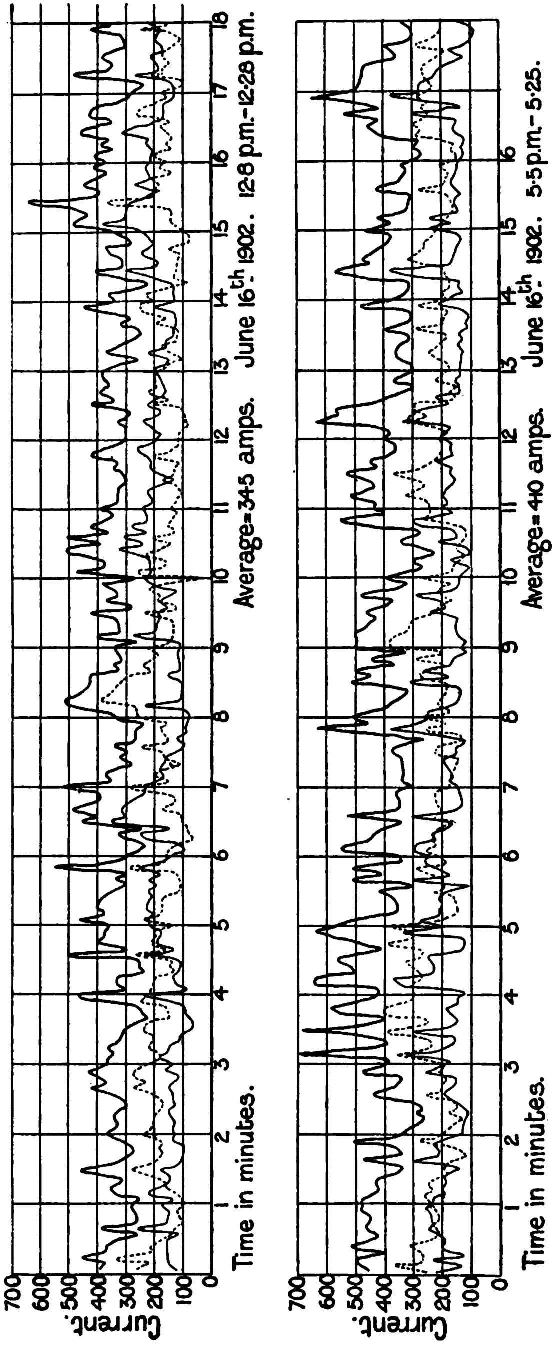


FIG. 18.—Output-Curve for a Number of Lifts.

measured by two Kent's Positive water meters, the results were taken every half-hour during the test, and the units generated were taken at the same time; as a check on the meters measuring the output, five-second readings were taken of the amperes registered by the Weston ammeters on the board during the whole test and the necessary corrections made. In this connection it may be stated that the output between 12 noon and 3 p.m. on the first day was 2,731 units, and on the second day 2,716 units; in each case the load was 16 trains and 17 electric lifts running. During the test of the Willans sets the average load on the 125-k.w. sets was about full normal load, while the 300-k.w. sets were also up to full normal load, *i.e.*, 600 amperes per machine. The average load on the Corliss sets during the test was 900 amperes each, or about 56 per cent. normal full load. The manner in which the load varied on the 300 and 800-k.w. sets is shown by Fig. 15, the 125-k.w. load being fairly steady, as these machines were feeding the sub-stations, and the variations were taken up to a large extent by the batteries. Under the above conditions the steam per kilowatt-hour for the Willans sets was 30·2 lbs., and for the Corliss sets 23·8 lbs.

From the author's experience there is no doubt in his mind that the Corliss type of engine is more economical than the Willans type as far as steam consumption is concerned; but there are other considerations, as the following will show. The first cost and floor space is very much in favour of the Willans type, but against this must be put the additional cost of condensers, etc., boilers, and buildings for boilers, coal, coal storage, and coal-handling plant, and additional labour in boiler-house, which latter may, however, be equalised by the Corliss type of engine requiring rather more attention than the Willans type in the matter of lubrication.

As to the question of upkeep and oil-consumption, careful records show the oil bill is much lower for the Willans engine, being 0·012 pence per unit generated, as against 0·028 for the Corliss. The repairs to the Willans, however, come out at 0·018 pence per unit, as against 0·008 pence for the Corliss engines. These repairs refer to a period of two and a-half years, and in estimating, the total units during that period have been taken. In order to give an idea of the working hours and output of the various sets the following figures may be useful:—

Description of Set.	Hours which Engine worked.	Units generated.	Maximum possible Units if Engine worked at normal full load.	Percentage of Full Load during period.
No. 1, 125 k.w. Willans	2,683	313,637	335,000	93·5
No. 2, 125 k.w. ,,	4,703	500,567	588,000	85·0
No. 3, 300 k.w. ,,	9,524	2,599,758	2,860,000	91·0
No. 4, 300 k.w. ,,	9,555	2,266,433	2,865,000	79·2
No. 5, 800 k.w. Corliss	9,012	3,855,595	7,200,000	53·8
No. 6, 800 k.w. ,,	8,606	4,073,635	6,880,000	59·2

It will thus be seen that if the Corliss engines were loaded in a similar

manner to the Willans, the repairs per unit would be about half that given above. Again, in arriving at the cost of the Corliss engine repairs, new high- and low-pressure pistons for each engine is included, which in ordinary conditions would not come under the item of repairs. These pistons were changed, as they were considered too light for their work, and amount to 75 per cent. of the total cost.

It is not so much a question of "low- *v.* high-speed engines" as some suitable form of Corliss valve gear to run at high speeds *v.* high-speed central or piston valve engines. If one could only obtain the

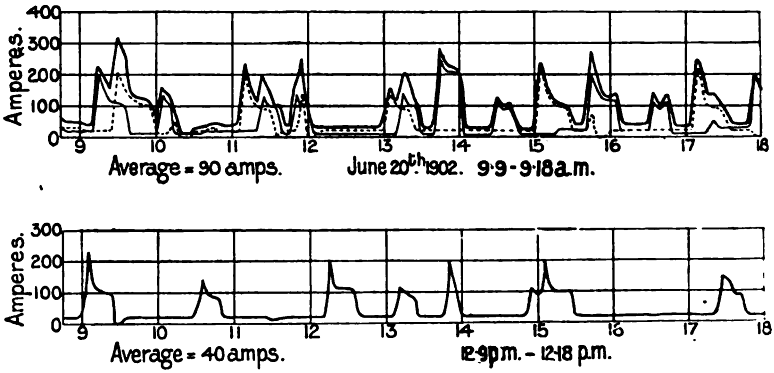


FIG. 19.—Output-Curve, Clapham Extension Lifts.

Corliss engine economy with the low first cost and floor-space per unit of the Willans, a happy solution of the problem would be attained. This end is to a very great extent secured in the Ferranti engine, in which the steam-consumption is only a trifle higher than in the Corliss, and speeds very nearly as high as the Willans obtain. The

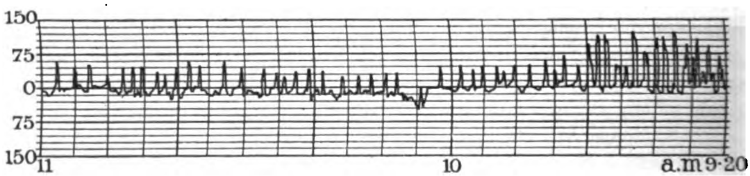


FIG. 20.—Recording Ammeter Diagram, Clapham Extension Lift.

author is unfortunately unable to state definitely the steam-consumption per kilowatt-hour of the 400-k.w. Ferranti E.C.C. set installed at present. But, if one can depend on the makers' guarantee, it closely follows the Corless in steam-consumption.

ALL DAY TEST, APRIL 8TH, 1903.

On April 8th, 1903, an all-day test of the generating station output was made, starting at 6 a.m. and ending 12 midnight. The coal used was weighed and also measured in the ordinary way by the measuring

shoots, the coal weighed was 39·6 tons, and the weight as ascertained by the measuring shoots was 39·97 tons, showing that the latter method was accurate to within less than one per cent. The feed water was measured by using three tanks, one from which the feed pumps drew the water and the other with gauge glasses were filled alternately to a mark and emptied into the first tank. The condensed water from the main generating engines as well as the air and circulating water pumps was passed through two Kent's Positive water meters, and readings taken every hour. The coal fed into the hopper over the mechanical stokers and the units generated as well as the train-miles were also taken hourly. Owing to the turnstile system, which was in operation during the all-day test given for January, 1894, having been discontinued, and the ticket system put in operation, it was not possible to ascertain the number of passengers per hour, but in other respects the tests were similar, and show very clearly the results obtained in the two stations. The curves Fig. 16 show the results of the test plotted. It may be mentioned that the weight of coal used by the hydraulic pumping engines was determined by a previous test extending over a week, with a separately fired boiler. The coal used during the test is known as Broomhill, and careful samples were taken during the test from each 2 cwt. weighed for analysis, the result of which showed a calorific value of 13,200 B.Th.U. for dry sample ; the moisture in the coal was 8·16 per cent., and the ash 5·6 per cent.

Careful tests were also made of the flue gases, and the average of 10 samples taken during the day showed 10·3 per cent. of CO_2.

Total coal used, 39·6 tons	88,704 lbs.
„ „ „ by hydraulic engines	13,440 „
„ „ „ „ generating „	75,264 „
„ water fed into boilers	697,515 „
Water evaporated per lb. of coal at 150° F. ...	7·86 „
„ „ „ „ from & at 212° F.	8·60 „
Units (Board of Trade)	21,470 units
Condensed water measured including steam used on condensing plant	512,780 lbs.
Steam per unit (including condenser)	23·88 „
Coal „ „ „	3·5 „
Calorific value of dry coal	13,300 B.T.U.

Electric *v.* Hydraulic Lifts.

In the matter of easy control and steady working the electric lift cannot be said to be as perfect as the hydraulic, but from the point of view of first cost and total working expenses it is so far in advance of the hydraulic lift that it can safely be said more than to hold its own. The figures given are based upon the total number of complete journeys made by the lifts, and, for convenience of comparison with the cost of transportation in a horizontal direction, the total distance travelled vertically is given in "lift-miles." It would, perhaps, be better to use an expression like "ton-miles," which is more satisfactory than "train-miles," when dealing with railways or tramways. However, in the

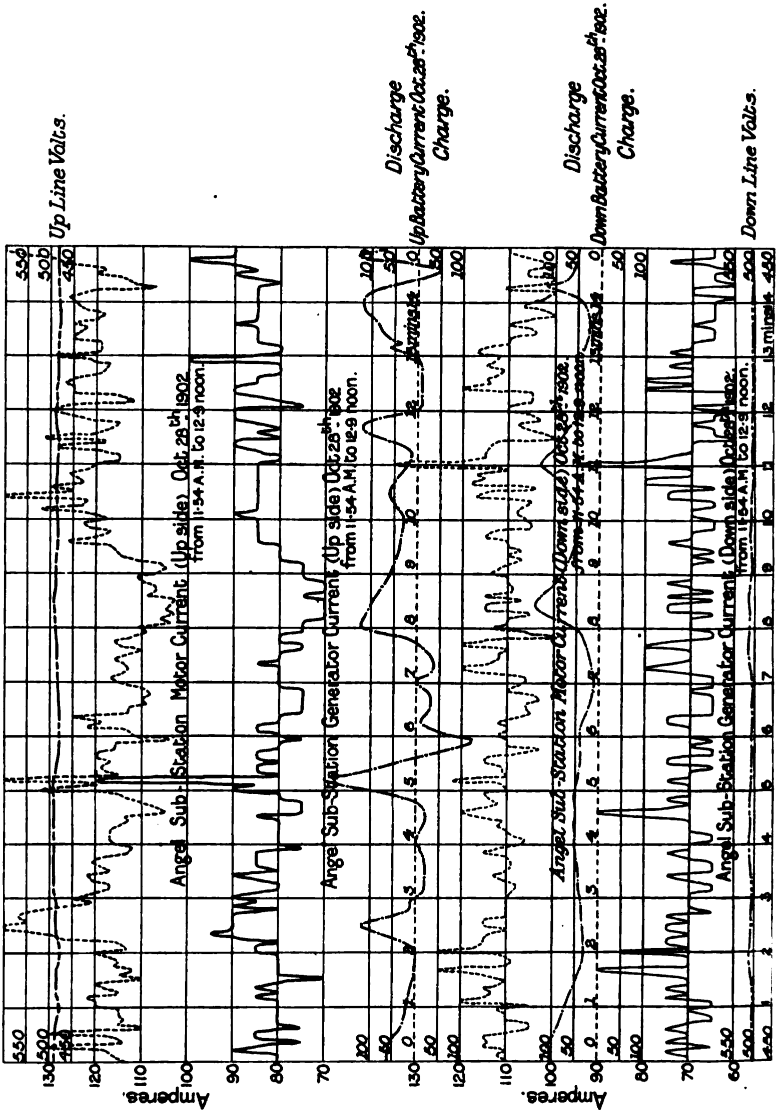


FIG. 21.—Record of Angel Sub-station Tests.

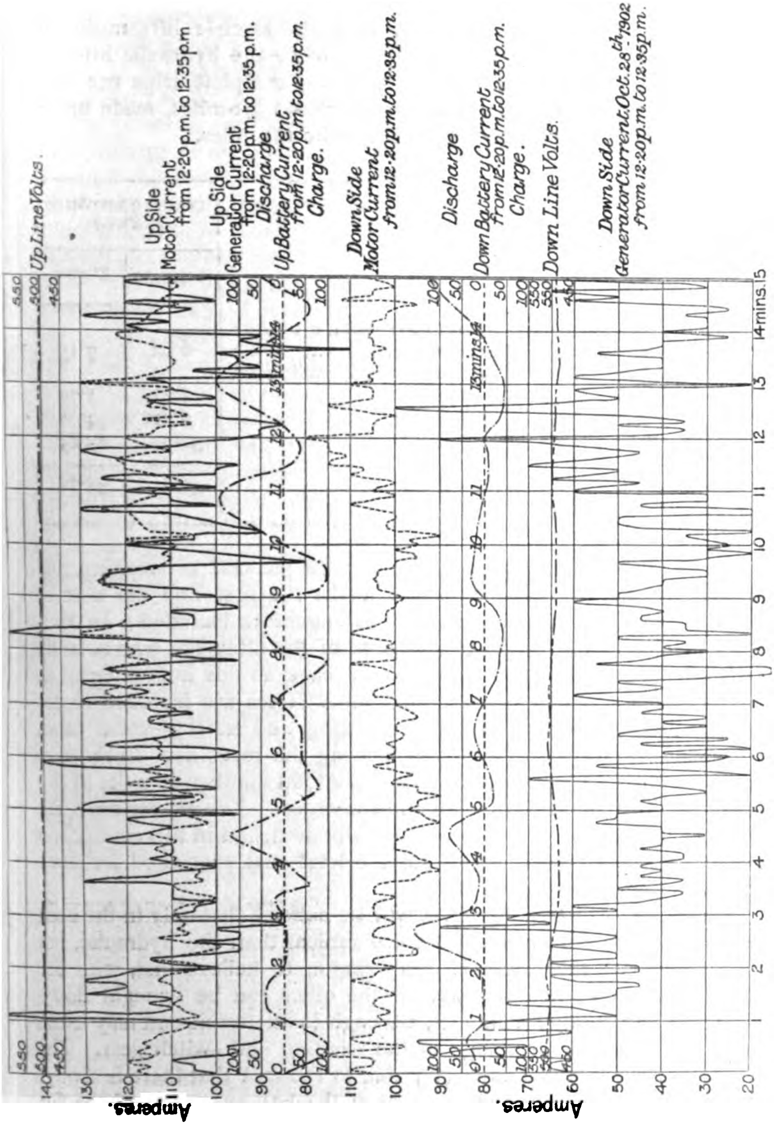


FIG. 22.—Record of Angel Sub-station Tests.

case of lifts, whether electric or hydraulic, the tonnage is complicated by the value of the balance weight, and the author does not see how the ton-mile basis can be applied in the same manner as in a train or tram.

For the half-year ending June, 1902, the electric lifts made an average of 4,254 complete trips per day, while the hydraulic lifts for the same period made an average of 2,209 complete trips per day. The total mileage for six months was 27,800 lift-miles, made up of 20,500 electric lift-miles and 7,300 hydraulic lift-miles.

	Cost per Lift-Mile in Pence.	
	Hydraulic.	Electric.
Labour, including mechanics, greasers, etc., but exclusive of cage attendant	6·02	7·15
Oil, waste, and other stores, including switch or valve gear and motor spares	1·41	1·79
Rope-renewals	2·12	4·02
Power-costs	32·50	15·85
Total	42·05	28·81

The above table shows the difference in the cost of working, and perhaps requires a little explanation. In the first line the cost of foreman, mechanics, greasers, and labourers is included; in fact, every item of labour, with the exception of the attendant who actually pulls the rope or works the switch in the cage, as this item is equal in both systems. With oil, waste, and other stores are included motor brushes, switch contacts, hydraulic packing, and starting valve parts. Rope renewals includes the cost of putting the ropes on. In the case of electric lifts the power-costs means the total number of units at the generated cost, including sub-station charges. The power-costs for hydraulics is the cost of pumping the water used, and in this connection it may be interesting to state that the total coal consumed for each system is practically the same.

Analysing the above figures, it will be noticed that only in the item for power is the electric lift more economical than the hydraulic, but the author feels that there is every reason to believe that, with the exception of "oil and other stores," the other can be brought down to the level of the hydraulic lifts, although to attain this end may mean a radical change in the design of the winding and switch gear. The increased cost of labour is largely due to the fact that there is always a man in charge of the motors, either at the bottom or top of the lift shaft, and this item is absent in the hydraulic system. The switch or controlling gear is also more complicated than necessary, and requires an amount of attention that will undoubtedly be reduced in future designs. In the matter of rope-renewals, again, the hydraulic lift scores; but there is room for improvement. With the motor at the

bottom of the shaft the ropes are longer and go over a number of guide-pulleys, which not only affects the life of the rope but adds to the cost of replacement. In many places, on account of the head-room available, it was necessary to make these guide-pulleys smaller than they otherwise would have been; with the motors at the top of the shaft a number of the pulleys are done away with, and the ropes are about the same length as in the case of the hydraulic lifts. Again the S form of drive is capable of improvement from the point of view of rope-renewals; all rope makers' and users' experience goes to prove that bending a rope in one direction and then reversing the bend has a very bad effect on the life of the rope. Even under existing conditions the electric lift shows itself to be far more economical than the hydraulic, and given the improvement outlined above there is no doubt that the electric lifts will supersede the hydraulic. Indeed, where the power has to be transmitted any distance, the hydraulic lift is out of the question. Looked at from the central station point of view, although the peaks due to a lift load are infinitely worse than those of a train or tram load, if there are enough lifts on the station the maximum variation of load is not very great, and if combined with that of a traction load the peaks are reduced instead of increased. Fig. 17 shows diagrams taken by a recording ammeter for single lifts, and Fig. 18 shows the output curve for a number of lifts. Fig. 19 shows the curve due to the lifts on the Clapham extension, from which it will be seen that a small number of lifts give a very unsatisfactory load curve; these peaks are, however, taken up by the battery and are shown on the recorder diagram, Fig. 20.

SUB-STATION EFFICIENCY.

At the Angel sub-station the following tests were made to ascertain the efficiency. Five-second readings were taken, over periods of a quarter of an hour, of the high-tension volts at the generating-station, the high-tension volts at the sub-station, the amperes in the high-tension feeders which correspond with the current in the motor armature of the reducer, the generator, armature current, and the 'bus-bar voltage. The efficiency of transmission and transformation is therefore—

$$\frac{(\text{Motor amperes} + \text{Generator amperes}) \times \text{'Bus-bar volts}}{\text{Motor amperes} \times \text{Generating-station volts}}.$$

The sub-station efficiency is, of course, lower, as the power to drive the Highfield booster and the battery losses must be taken into account. The battery efficiency was obtained by putting two Vulcan meters in series, one reading the charge and the other the discharge. The result of some months' daily readings were taken, and the meters reversed so as to eliminate any error due to the meters. The average efficiency over this period comes out at 88 per cent. This high figure is reached as the battery is always working on the flat part of the voltage curve. On deducting these losses from the energy given to the 'bus-bars, the useful output of the sub-station is obtained.

Two sets of tests were made, one for four periods of 15 minutes during the mid-day and the other for three periods in the afternoon,

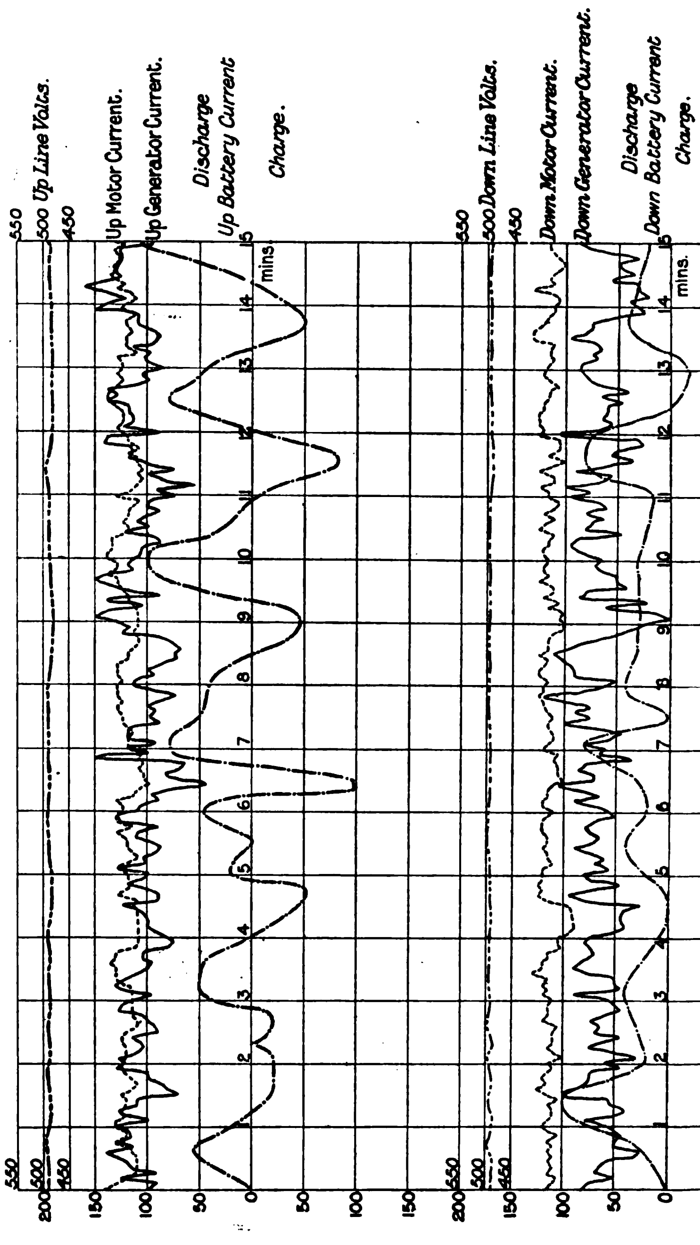


FIG. 23.—Angel Sub-station Tests. Record taken Nov. 11, 1902, from 5.30 to 5.45 p.m.

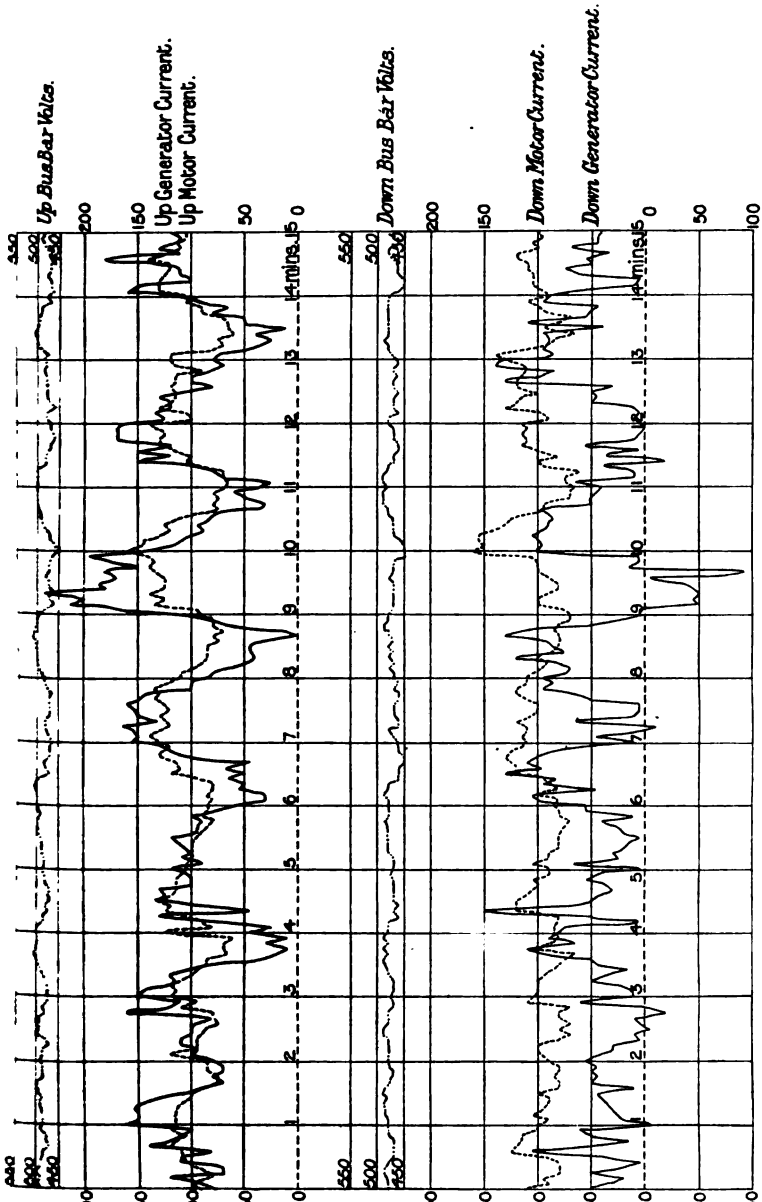


FIG. 24.—Angel Sub-station Tests. Record taken Dec. 15, 1902, from 4.41 to 4.56 p.m.

so as to get the efficiency under all conditions. The results of these tests are given in Tables S I., II., III., pp. 60–62, and the curves shown in Figs. 21–24.

It will be noticed from the curves that while the currents in the reducer motor-armatures are fairly steady, the generator-armatures currents vary considerably, showing that the reducers do a considerable amount of balancing. The effect of running the machines uncoupled is clearly shown in the curve Fig. 21 from 11.54 a.m. to 12.9 p.m.

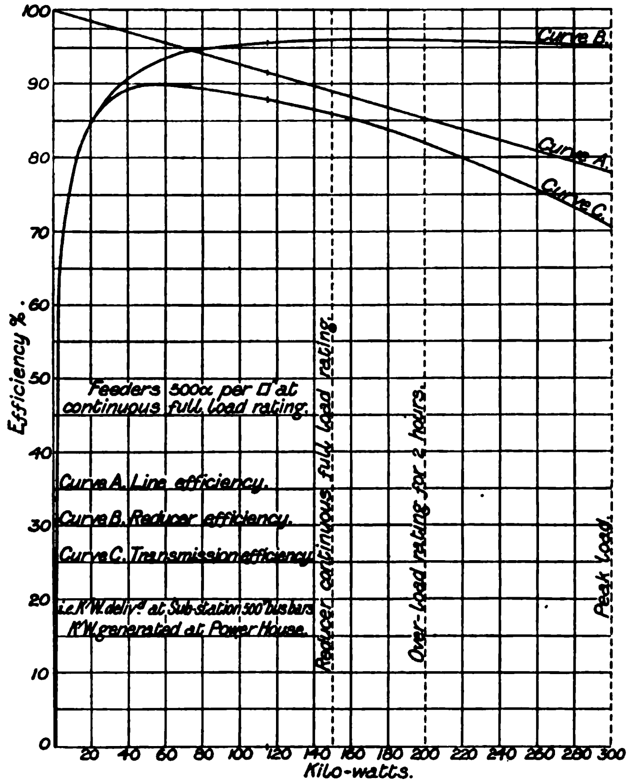


FIG. 25.—Angel Sub-station. Calculation of Efficiency.

From the curve it will be noticed that the motor current is always higher than the generator-armature current, and that the variations in the former exactly follow those in the latter. The balancing in this case is taken up by the batteries. The efficiency of transformation during this test is higher than in the other tests taken at this period of the day, and is no doubt due to the reducers not acting as balancers. Compared with the curve, Fig. 22, taken during the following quarter of an hour, it will be seen that the load on the up side of the system is heavier than on the down side, and that a portion of the up-side load is taken by the down-side motor, the average amperes delivered to the

up 'bus-bars being 225, while the amperes delivered to those of the down side were 149·5. At the same time the amperes delivered to the reducers from the generating-station were nearly equal on both sides of the system, being 113 on the up and 102·28 on the down side. The battery on the up side also did more work, both discharging and charging, than the down-side battery. The average efficiency of transmission during the four tests was 91·6 per cent., that of the transmission and transformation 84·15 per cent., while the transformation efficiency was 92 per cent. Allowing for the waste in the Highfield boosters and battery, the net efficiency of the sub-station was 81·65 per cent.

The second set of tests was taken on November 11, 1902, from 5.30 p.m. to 5.45 p.m., when the load on the sub-station was heavier. Fig. 23 shows the result of one quarter-hour from 5.30 to 5.45 p.m. In this case the down side has again less load than the up side, but not to the same extent as in the case recorded in Fig. 22. It will be seen that the batteries are also doing more work, at times taking peaks almost equivalent to half the total reducer load, and in the next few seconds changing almost to the same extent. The results of the three evening tests are tabulated in Table S II. The average transmission efficiency was 90·9 per cent., the transmission and transformation efficiency was 86·2 per cent., and the transformation efficiency 95 per cent. Allowing for the batteries and boosters as before, the net substation efficiency was 81·8 per cent. Inspection of the voltage curves shows that the voltage regulation is all that could be desired, although the load sometimes rises to 700 amperes, while the maximum drain on the generating station for this peak was only 245 amperes.

The effect of running the sub-station without the batteries was then tried, and the result of two quarter-hour tests given in Table S III. and curves Fig. 24. The shape of the curves is altered, the voltage regulation not being nearly so good as in the other cases, although it is still better than found on many lighting circuits. The motor- and generator-armature current follow each other on the up side, although varying considerably, while the down-side record shows that a large amount of balancing is taking place. The extent of this balancing is clearly marked at one point where the up generator-armature current is 235 amperes, the motor current being 135, at the same instant the down motor current is 80 amperes and the generator current 50 amperes in the reverse direction; or, in other words, the generator-armature has become a motor-armature and pumps current from the down to the up side of the system. It will also be noticed that the amperes from the generating-station on the up side vary from 60 to 160, while with the batteries this current is very nearly constant. Under these conditions the average efficiency of transmission was 91·1 per cent., the transmission and transformation efficiency being 83 per cent., and the transformation efficiency 91·1 per cent.; the low transformation efficiency being no doubt due to the amount of balancing taken up by the reducers.

It may be argued that a better nett efficiency is obtained without the batteries, but it must be remembered that the sub-station is not at

present fully loaded, and that by using the batteries the peaks at the generating-station on the high-tension feeders are practically avoided. Further, the batteries are used in cases of emergency not only for the lift and lighting circuits, but also to feed the working conductor and have a value in this direction which is rather hard to estimate. Fig. 25 gives the calculated efficiencies for this sub-station, and it will be noted

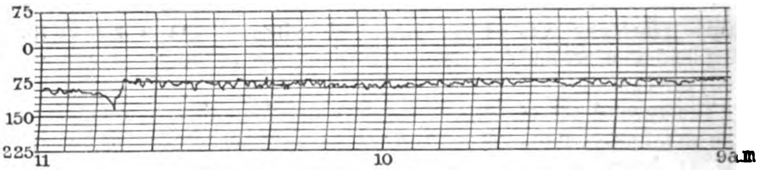


FIG. 26.—Amperes at 1000 volts, Angel feeder.

that the values are somewhat higher than the actual efficiencies obtained in the tests.

The recorder charts in connection with this sub-station are also interesting. Fig. 26 shows the current in the down high-tension feeder. The current is practically constant at 80 amperes from 9 a.m. to

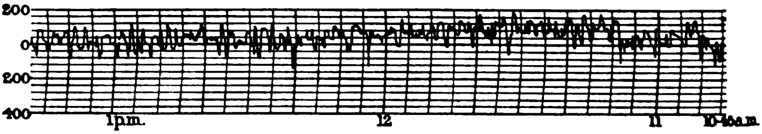


FIG. 27.—Battery Amperes, Angel Sub-station.

10.45 a.m., and then increases to 100 amperes, at which it remains fairly steady for five hours during which the battery is being charged. Fig. 27 shows the current going into and and leaving the battery; it will be noticed that at 10.45 a.m. the discharge on the whole is transferred to a charge on the whole, and this corresponds with the increased amperes

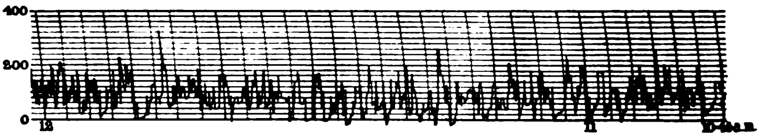


FIG. 28.—Amperes to Working Conductor, Angel Sub-station.

in the high-tension feeder. Fig. 28 shows the amperes to the working conductor during the same period, where peaks of 400 amperes are reached, while the sub-station feeder current remains at 75 amperes on the down side of the system. Fig. 29 gives the voltmeter chart for a whole day; from 1 p.m. to 4.30 p.m. there is more variation than at any other period of the day. This is due to the want of regulation on the Edison-Hopkinson machines at Stockwell, which it will be remembered were not actually designed to run as motor-generators.

The difference between a battery working with a reversible booster and simply floating on the 'bus-bar is shown by Fig. 30, which is a chart from the battery at London Bridge sub-station working in connection with the reducers; the peaks seldom reach 80 amperes, and

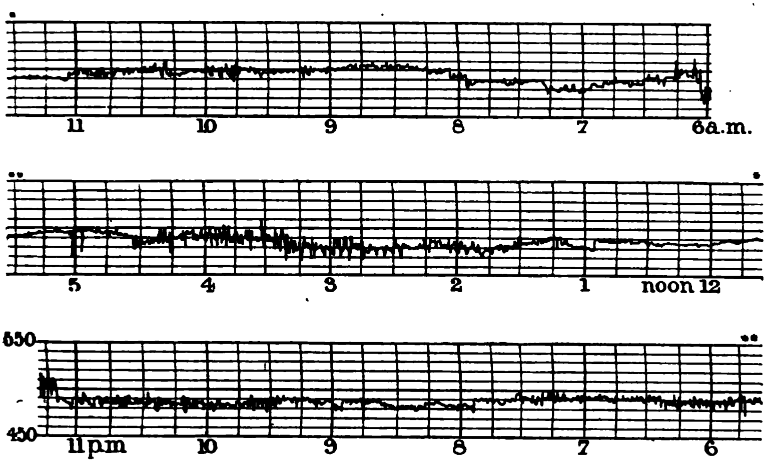


FIG. 29.—Angel 'Bus-bar Volts.

the average discharge is only about 30 amperes. From 11.35 a.m. to 1.25 p.m. the battery is being charged. A reference to the voltage chart, Fig. 31, explains why the battery does so little without a reversible booster.

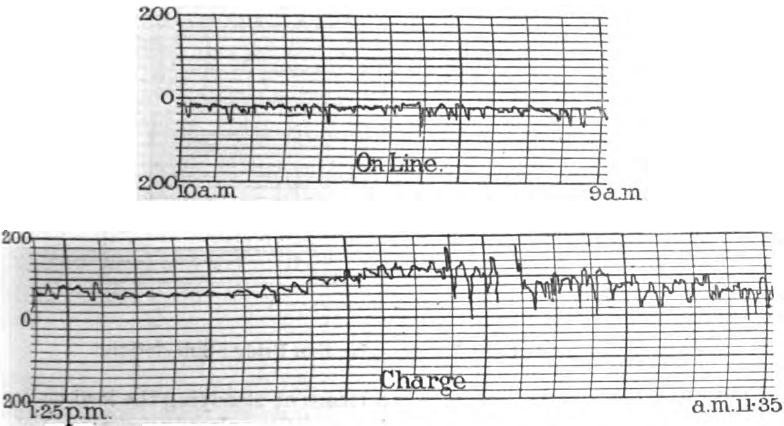


FIG. 30.—London Bridge Sub-station Amperes. Battery Floating.

Shortly after the opening of the Moorgate Street extension it was necessary to run on the plain three-wire system; that is to say, the high-tension service was discontinued temporarily, and the high-tension feeders coupled direct to the low-tension 'bus-bars at the generating-

station. In this manner London Bridge sub-station was used as a battery station, and the performance of the battery under these conditions is shown on Fig. 32. During ordinary working the battery took peaks of 175 to 200 amperes discharge, and charge to the extent of 50 to 60 amperes. The corresponding voltage chart is shown on Fig. 33 and is very steady considering the conditions. From 6.15 to

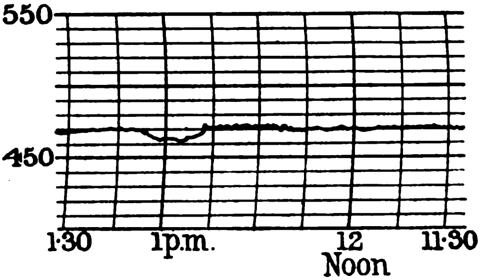


FIG. 31.—'Bus-bar Volts, London Bridge.

7.5 a.m. the battery was off and the voltage drop was considerably more than with the battery; from 7.5 to 7.50 a.m. the battery was charging, and this gave a steadier voltage although lower than without the battery. At 8.45 a.m., when the load was getting heavy, the battery discharged, and the result is at once noticeable on the voltage. In order to get some

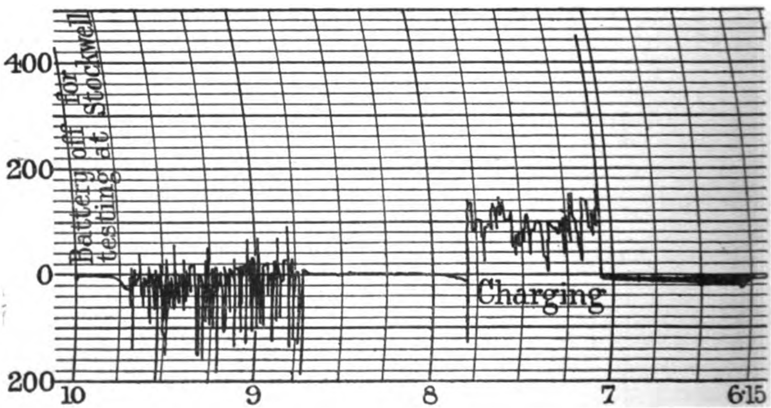


FIG. 32.—Battery Amperes, London Bridge Sub-station.

idea of the value of the battery as a means of steadying the load on the generating-station working under the conditions already described, five-seconds observations were taken at the generating-station of the amperes going out in each feeder on one side of the system, with and without the batteries. Fig. 34 gives the result. With the batteries on the line as regulators from 9.25 to 9.40 a.m., and without the batteries from 9.45 to 10 a.m., the number of trains and lifts running during the two tests

were the same. Fig. 33 shows the result in voltage variation. Fig. 34 indicates that the battery steadies the load not only on the sub-station feeder, but on the Stockwell and Kennington feeders as well. The amount is not very great, but it is noticeable. As to the total value, with the battery the maximum peaks were 575 amperes once, and 560 amperes four times, and the minima were 330 amperes once, and 370 amperes four times; whilst, without the battery, the maxima were 700 once, 600 once, and 575, or a little over, eight times, whilst the minimum was 280 once, and 320 several times. The maximum peaks were, therefore, about 21 per cent. greater without the battery than with. The average amperes during the test were 471 without and 452 with the battery, or the average load on the generating-station was about 4·2 per cent. lower with the battery. From the general shape of the peaks during the two tests, it would appear that to run without the battery would require generators with an output of about 10 per cent. greater than with the battery.

As already referred to, a large battery has a value as a reserve which

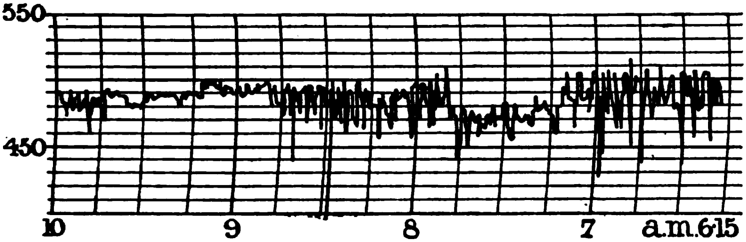


FIG. 33.—Up-line Volts.

is rather hard to estimate, and this is clearly shown by Figs. 35 and 36 giving the recorder charts for the Angel sub-station on one occasion when London Bridge sub-station was thrown out of use by a short-circuit on the back of one of the switchboard panels. Fig. 35 shows the battery amperes before and after London Bridge sub-station was shut down. After the "short" the Angel sub-station took the whole load and the battery gave discharge peaks up to 400 amperes, also charging up to 200 amperes, the pressure at the extreme end of the line being only reduced by 20 volts, and at London Bridge the working conductor voltage was practically unaltered, or at least the drop in no way interfered with the working of the traffic or caused inconvenience in the matter of train-lighting.

Balancing and Rail Drop.

Mention has already been made of the useful effects of the reducers at the sub-station acting as balancers, and, in addition, the balance at Moorgate Street station takes up most of the out-of-balance load as shown by the curve, Fig. 37.

With such good balancing the rail drop is naturally small, and it would appear that the three-wire system as installed on the City and

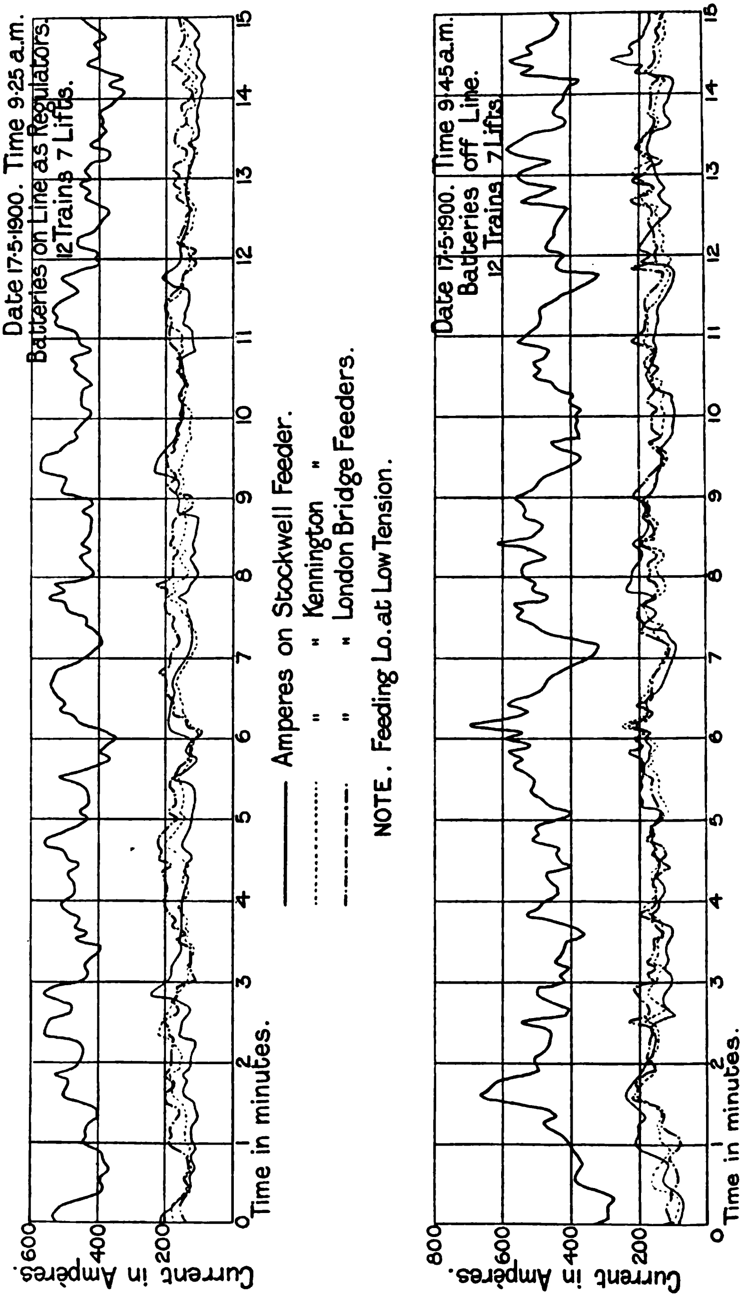


FIG. 34.—Generating Station Output, with and without Batteries, at London Bridge.

South London Railway has not yet reached its limits in regard either to the distribution or to the Board of Trade rail drop. An inspection of the recorder charts taken at three points along the line show that the rail drop does not increase with the distance from the generating-station. In fact it is very little greater at the Angel than it is at London Bridge or at Moorgate Street stations. Fig. 38 shows the drop between the generating-station and London Bridge, Fig. 39 the drop at Moorgate Street station, and Fig. 40 the drop between the generating-station and the Angel.

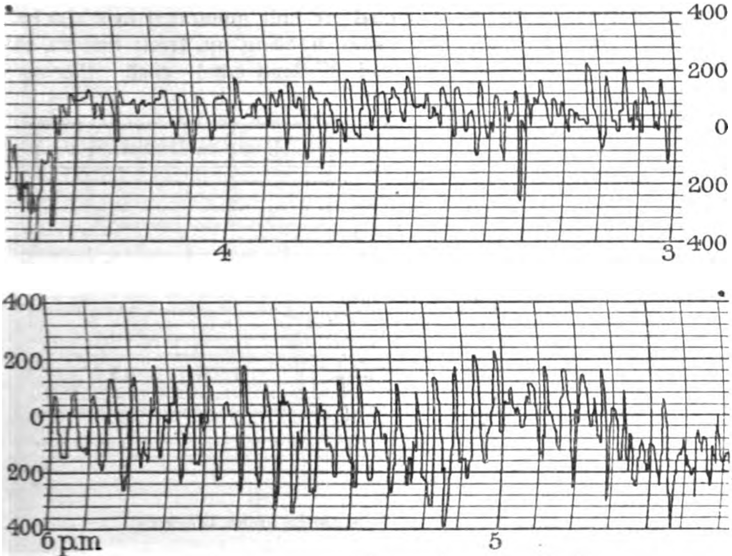


Fig. 35.—Amperes, Angel Sub-station alone Working.

Overall Efficiency of Distribution.

About one-half of the total energy generated is delivered to the line at 500 volts, or direct without any transformation; the efficiency at the various points along the line being as follows:—

Stockwell	99·3 per cent.
Kennington... ... ...:	96·6 „
London Bridge	86·0 „
Angel	81·6 „

The average efficiency over the whole system being 90·9 or, say, 91 per cent. From this must be deducted the loss in the working conductor before the nett efficiency of distribution to the locomotives can be obtained. Taking the average current density in the working conductor with the average train service, the maximum loss between the feeding points farthest apart is just over 1 per cent., and with the feeding points closer the loss is just under 1 per cent., so that the average loss between the end of the feeders and the locomotives is well covered by 1 per cent. The nett efficiency of transmission from the switchboard in the generating-station to the locomotives is thus 90 per cent.

Cost per Unit.

The cost per unit for the half year ending June, 1902, is given below. The figures refer only to the works cost. To compare the results with a lighting station, the cost of management, directors, office and legal expenses, insurance, etc., should be added; but as the above items are divided over all departments of the railway, and it is purely a matter of opinion what percentage should be charged to generating only, the item can be omitted without materially affecting the results, and a comparison made on the basis of works costs only. The units generated were 3,781,087. The coal per unit generated over the half-year, including all standing-by losses, lighting up, fresh boilers, etc., was 3·9 lbs. of North-country and Midland small coal. During a

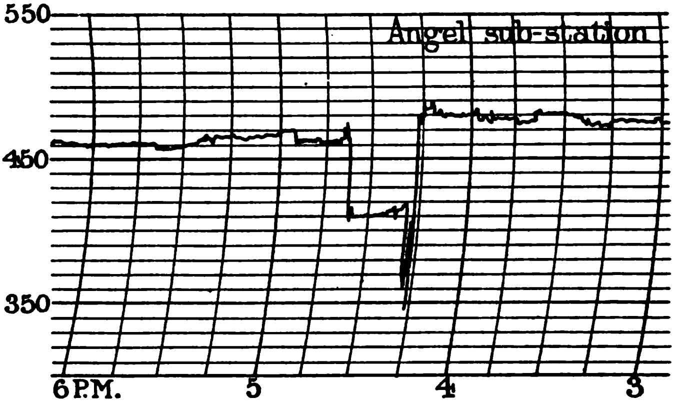


Fig. 36.—Volts, Angel Sub-station alone Working.

month of this period when a coal of a slightly higher calorific value was used, the coal per unit was 3·28 lbs., including all losses as before.

Cost per Unit Generated in Pence.

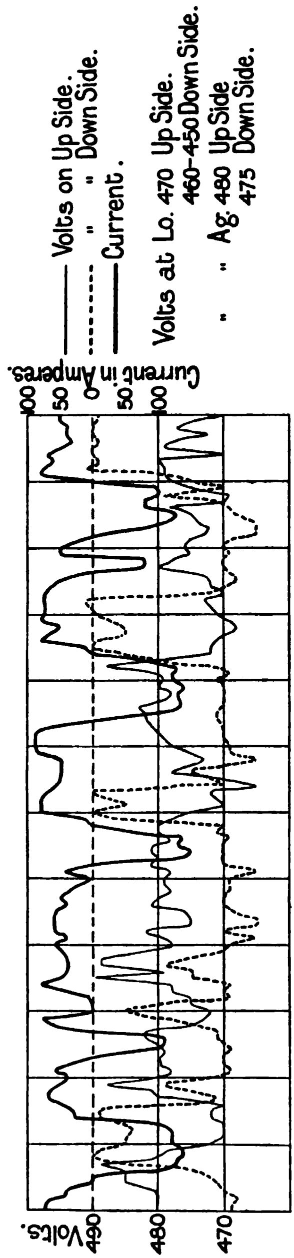
Coal	0·310
Water, oil waste, and other stores	0·046
Wages, including Engineer in charge ...	0·056
Repairs and maintenance	0·028
Total works costs	0·440
Sub-station charges, including those of battery, maintenance, etc.	0·035
Load factor	49·2 per cent.

Results of Working of Locomotives.

For the same period the ton-miles were 27,832,000, and if the units per ton-mile on board the locomotive are taken, namely, 0·0552, the coal per ton-mile was 0·215 lb. or 3·45 ounces.

In order to place the results on a basis for comparison with

steam locomotives, the coal per ton-mile at the switchboard should be taken, and this amounted to 0·237 lb. This figure includes all boiler-house losses, such as lighting up boilers and banking fires, etc. If compared with main-line locomotives the result is in favour of the latter, but it must be remembered that the energy spent upon accelerating main-line trains is only a fraction of that spent on a line with short sections, and, as has already been shown by the author in his paper* on "Tractive Resistance in Tunnels," the traction resistance per ton is at least double that obtained in main-line practice. The published results obtained with steam locomotives are usually taken over short periods, and refer to special tests from which all standing-by losses are excluded. When the time arrives at which electric locomotives can be tried under conditions similar to those of steam locomotives, there is every reason to believe that the coal per ton-mile will be in favour of the electric locomotive.



Lo. = London Bridge. Ag. = Angel.

FIG. 37.—Balancer Volts and Amperes.

While on the question of locomotives, it may be interesting to give some details of their upkeep. With the old type of locomotive with Gramme surface-wound armatures, the chief source of trouble was the failure of the armature winding due to its shifting on the core, thereby causing short-circuiting and burning-out. The field-magnet winding seldom or never gave any trouble, due no doubt to the liberal allowance of copper, and to the bobbins being on the earth side,

* This Journal, 1899, vol. 28, p. 508.

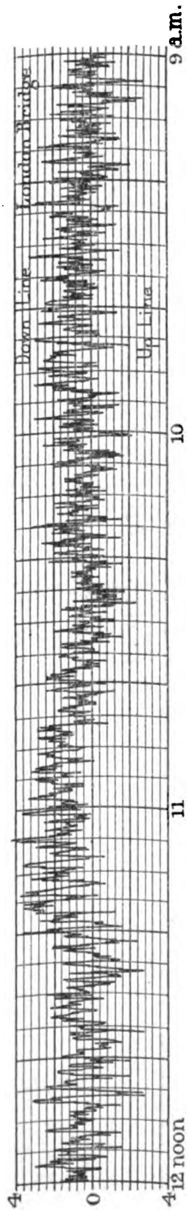


FIG. 38.—Rail-Drop between Generating Station and London Bridge.

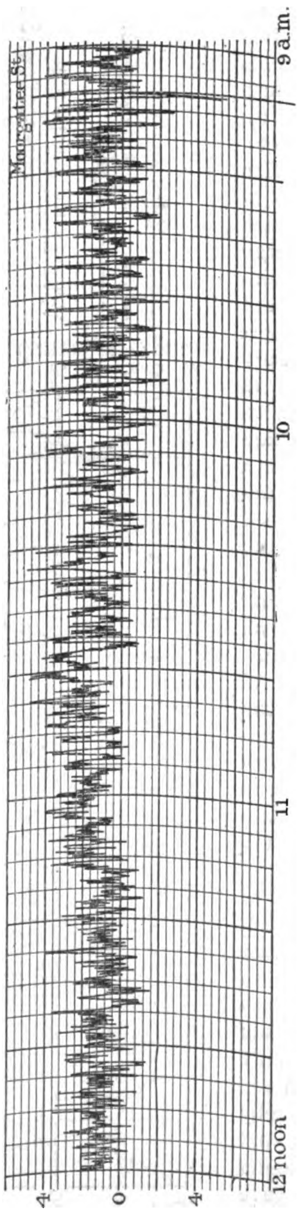
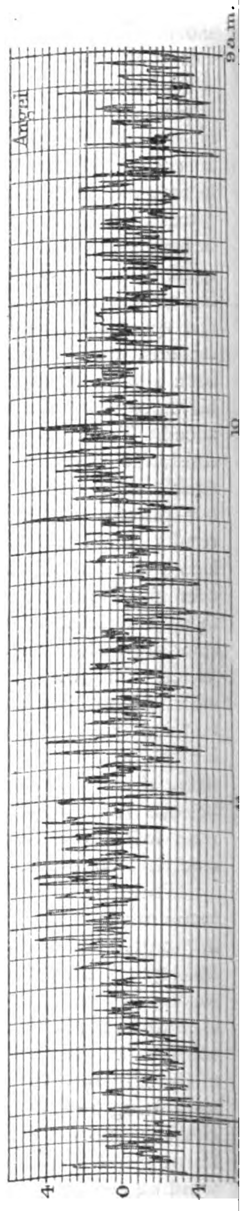


FIG. 39.—Rail-Drop between Generating Station and Moorgate Street Station.



and therefore subjected only to a pressure equivalent to the drop of volts across the winding. Taking the history of thirty of these armatures in everyday use, after running 100,000 miles the winding began to show signs of failure, at between 100,000 and 120,000 miles the failure became more frequent, and when an armature ran 150,000 miles it was generally necessary to re-wind it, the cost being about £20. 180,000 miles seems to have been the best record with a single winding failure, and several cases of 175,000 have been recorded, the average being 100,000 miles. Cases have arisen where failures took place after 1,000 miles or less, but as a rule some external cause was discovered. To obtain the above results the locomotives were only allowed to run about one month, when the armatures were taken out and cleaned, thoroughly varnished with shellac, and baked in an oven; if this precaution was neglected trouble always resulted.

The later and more powerful locomotives which were described in the author's paper on "Electric Locomotives"* have not been in use long enough to institute a comparison on exactly similar lines, but the records so far show that the slot-wound armature is vastly more satisfactory than the smooth-core armature. Some of these locomotives ran 13 months continuously without coming into the repair shops for overhauling, the mileage being 46,000. The highest mileage yet recorded is 110,000 continuous running, the average being about 75,000 miles; and from our experience there appears to be no reason why these figures should not reach three or four times their present magnitude before winding troubles arise. In the 32 locomotives of this class, of course, armature failures have occurred, some due to external causes, and others to defective insulation; but 50 armatures out of the above locomotives have run an aggregate of 3,245,900 miles without a single winding failure. This is a very satisfactory record, and if the general result of the trustworthiness of the locomotives is expressed as a percentage of the time lost through armature failures, it comes out at 0·16 per cent. Or, for the past six months, of the total running time, only 0·16 per cent. was lost.

The maintenance and running cost are also low, as shown by the following figures:—

	Pence.
Oil waste and other stores used on locomotives	0·098 per train-mile.
Repairs, materials used on locomotives...	0·137 ,, ,,
Wages spent on repairs	0·230 ,, ,,
Total cost per train-mile, including all salaries and wages connected with the generating of power, running of locomotives, coal, water, and other stores, material, and wages for repairs ...	4·61 pence.

* This Journal, 1899, vol. 28, p. 508.

TABLE S. I.

Date. Oct. 28, 1902. Time.		Generating Station.		Angel Sub-station.				Kilowatts.			Efficiency.			Remarks.
				Amperes.		Volts.								
		Amperes.	Volts.	Motor Armature.	Generator Armature.	High Tension.	Bus-bar.	To Feeders at Generating Station.	To Reducers at Sub-station.	To Sub-station Bus-bars.	Transmission.	Transformation.	Transmission and Transformation.	
11.15 a.m. to 11.30 a.m.	Up ...	99·2	1,000	99·2	108·8	403	495	99·20	89·20	102·00	Per cent.	Per cent.	Per cent.	Average kilowatts put into battery = 6·96, of which 12 per cent. is lost = 0·835 K.W.
	Down	106·7	995	106·7	28·1	410	495	106·25	96·60	63·75				
	Total	...	...	...	...	...	...	205·45	185·80	165·75	90·6	89·4	80·7	
11.54 a.m. to 12.9 p.m.	Up ...	118·4	1,000	118·4	82·2	400	490	118·40	105·40	101·00				Average kilowatts lost in Highfield Booster = 6·86.
	Down	110·4	1,000	110·4	70·25	410	500	110·00	103·00	93·30				
	Total	...	...	...	...	...	...	228·40	208·40	194·30	91·3	93·2	85·2	
12.20 p.m. to 12.35 p.m.	Up ...	113·00	1,000	113·00	112·4	400	490	113·00	106·00	110·30				Average kilowatts to line: = 181·4 − 7·69 = 174·15.
	Down	102·28	1,000	102·28	47·17	407	495	102·28	92·40	74·10				
	Total	...	...	...	...	...	...	215·28	198·40	184·40	92·4	93·1	85·7	
12.45 p.m. to 1 p.m.	Up ...	113·20	1,000	113·20	109·9	400	490	113·20	107·50	109·00				Net efficiency: $= \frac{174·15}{213·5} \times \frac{100}{1}$ = 81·65 per cent.
	Down	102·04	1,000	102·04	48·47	406	485	102·04	90·80	73·00				
	Total	...	...	...	...	...	...	205·24	198·30	182·90	92·1	92·4	85·1	
	Average	...	...	...	...	...	...	213·59	...	181·21	91·6	92·0	84·15	

TABLE S. II.

Date. Nov. 11, 1902. Time.		Generating Station. Amperes.	Generating Station. Volts.	Angel Sub-station. Amperes. Motor Armature.	Angel Sub-station. Amperes. Generator Armature.	Angel Sub-station. Volts. High Tension.	Angel Sub-station. Volts. Bus-bar.	Kilowatts. To Feeders at Generating Station.	Kilowatts. To Reducers at Sub-station.	Kilowatts. To Sub-station Bus-bars.	Efficiency. Transmission.	Efficiency. Transformation.	Efficiency. Transmission and Transformation.	Remarks.
											Per cent.	Per cent.	Per cent.	
5.13 p.m. to 5.28 p.m.	Up ...	121·5	983	121·5	108	400	490	119·40	108·00	112·50				Average kilowatts put into battery = 29·25, of which 12 per cent. is lost = 3·51.
	Down	113·0	987	113·0	63	410	490	111·50	101·60	86·40				
	Total	...	...	...	...	...	...	230·90	209·60	198·90	90·8	95·0	86·3	
5.30 p.m. to 5.45 p.m.	Up ...	120·7	983	120·7	108	400	490	118·70	107·40	112·00				Average kilowatts wasted in Highfield Booster = 6·86.
	Down	113·0	987	113·0	64	400	490	111·50	101·60	86·75				
	Total	...	...	...	...	...	...	230·20	209·00	198·75	91·0	95·2	86·4	Average kilowatts to line :
5.50 p.m. to 6.5 p.m.	Up ...	125·0	985	125·0	112	400	490	123·00	111·20	116·00				= 199·68 − 10·37
	Down	113·0	987	113·0	61	410	490	111·40	101·70	85·40				= 189·31.
	Total	...	...	...	...	...	...	234·40	212·90	201·40	90·9	94·8	86·0	Nett efficiency : $= \frac{189·31}{231·80} \times \frac{100}{1}$
	Average	...	...	...	...	...	...	231·80		199·68	90·9	95·0	86·2	= 81·8 per cent.

TABLE S. III.

Date. / Time.		Generating Station.		Angel Sub-station.				Kilowatts.			Efficiency.			Remarks.
				Amperes.		Volts.								
		Amperes.	Volts.	Motor Armature.	Generator Armature.	High Tension.	Bus-bar.	To Feeders at Generating Stations.	To Reducers at Sub-station.	To Sub-station Bus-bars.	Transmission.	Transformation.	Transmission and Transformation.	
											Per cent.	Per cent.	Per ent.	
4.17 p.m. to 4.32 p.m.	Up ...	95	985	95	62	412	493	93·60	86·90	77·40				
	Down	98	990	98	70	423	479	97·00	88·40	80·60				
	Total	...	...	...	...	...	...	190·60	175·30	158·00	92·0	90·2	83·0	
4.41 p.m. to 4.56 p.m.	Up ...	104	985	104	102	405	482	102·40	92·30	99·35				
	Down	99	990	99	47	421	473	98·00	88·50	69·10				
	Tota	...	...	...	...	...	...	200·40	180·80	168·45	90·2	92·0	83·0	
	Average	...	...	...	...	...	...	195·50	...	163·22	91·1	91·1	83·0	

Professor C. A. CARUS-WILSON: Mr. McMahon is to be congratulated on the great efficiency to which he has brought his system. We are all glad to get further details of this railway, and I am sure he does not need to apologise in any way for bringing the matter before us. I want to draw attention to what seems to me the most important feature of this railway, namely, the method adopted of connecting the up and down track, in series, having 1,000 volts, 500 volts on the one and 500 volts on the other. The other details that have been described will no doubt give rise to discussion, but I think this is the unique feature of this railway. With this system it is necessary to use the track rails as the return. If that be not done, if you use two insulated conductor rails on both up and down lines, you may at any time get an earth of 1,000 volts; so that this system necessitates the use of the track rail as the return conductor. Now, with the track rail as a return, the risk of a short circuit is largely increased. I do not say that on this particular line the risk is serious, for a reason that I will allude to later on; but I think, generally speaking, it would be agreed that an electric railway with track return has a much greater risk than one with two insulated conductors. For this reason, that with track return if your motor circuit goes to ground at any point a short circuit is the inevitable result. But with two conductor rails it needs two such grounds simultaneously in order to get a short circuit. That seems to me to constitute an important claim for the consideration of the double insulated conductor rail. Of course, I am aware that there are many lines now running with track return, such as the Central London Railway, and in fact almost all the existing railways employ track return—I think with two exceptions—the Great Northern and City is the only line in London which has a double conductor rail, and the Mersey line has a double conductor rail; the Metropolitan and District lines are being equipped with double conductor rails—but at the present time the universal custom is no doubt to use a single conductor rail, with the track as return. It may be urged that in this particular instance there has been no serious accident, but there is an explanation for this, namely, that this line is unique in that it is worked with locomotives. I think that the time for the use of locomotives on electric railways of this class has practically passed. I do not mean to say that anything but locomotives can be used on this particular line; on account of the size of the tubes no other system of traction could be used. But I think this is the reason why this line has been running now for thirteen years and there has never been a serious accident on it. That is a splendid record for a line, but it is largely due to the fact that it has had the advantage of using electric locomotives. Where is the advantage of the electric locomotive, from the point of view of security? Simply in this, that you have the whole of your electric apparatus, the controlling arrangements, motors and cables—which are worst of all—contained in a single vehicle, which you can isolate completely, and insulate as much as ever you like, and which can be fireproofed *ad libitum*. In that way you can reduce the chance of accident practically to nil, and if a short circuit should occur it is harmless, and the people in the train may be quite unaware of it. Directly you go in for motor-cars the state of affairs is

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Prof. Carus-Wilson. entirely different. You have, to begin with, cables under the cars, motors under the cars, the controlling compartments are necessarily part of the car body, and in that way the risk of accident and of damage is greatly increased. The accident on the Paris Metropolitan Railway was indirectly due to the motor-car system, so also was the accident on the Liverpool Overhead Railway. With the motor-car system and the track rail as a return, you have great risk of accident, and as things stand now we cannot afford lightly to put aside the advantage of the double insulated third rail. I think the time will come when it will be a recognised necessity that every electric line has a double insulated third rail, simply for the security it gives against short circuits, the security lying mainly in this, that if you get a ground on any part of your motor circuit it does not in itself constitute a short circuit, and you can detect it before a second ground takes place. This is a great advantage, which you cannot have if your track rail is used as a return. On this account I think that a system which inevitably involves the use of track return is not very likely to be used in further extensions on other possible lines. It may be said, "There are lines running besides this one with great success with track return; for instance, the Central London Railway." Yes, but if you examine the trains on that railway carefully, you will find that they are not strictly motor-car trains. There are only four motors—two at each end of the train. The motor-truck is at one end of the car only, and entirely isolated; the electric apparatus is all contained in a steel cab separated from the passenger compartment. You have, in fact, locomotive conditions. If you look at the cars which are now being put on the Great Northern and City Railway, or which are being prepared for the Metropolitan Railway, you will see that the conditions are totally different. You must have the motors, not only at the two ends, but in the middle of the train, and the controller compartments as part of the car bodies, with the cables under the passenger compartments. Under those conditions the difficulties are so great that I think we shall be obliged to take advantage of everything that gives us additional security, and one of the greatest securities is a second insulated third rail. Therefore, whilst Mr. McMahon's system undoubtedly works well on the City and South London Railway, yet we can hardly expect to see it extended in other directions. In conclusion, I would like to compliment Mr. McMahon's company on the persistency with which they go on burrowing through London. From London Bridge they got up to Moorgate Street, then to the Angel. Now we hear they are going on to Euston; but I would suggest that the time has come for them to change the name of the Company, as "City and South London" is hardly appropriate to the new conditions.

Mr. Hobart. Mr. H. M. HOBART: I disagree with Professor Carus-Wilson's opinion as to the disadvantage of having a single rail return, because there would be a great disadvantage, with two insulated rails, in having one unknown ground on each of several trains, and to know that no breakdown would occur until another ground should develop. Mr. McMahon has attained excellent results on his road, and, it seems to me, in the face of great difficulties. He has utilised much of the

apparatus of his original system, and has transformed it into a very modern and novel system in which the results show great economy. But I presume if he had to do the work all over again he would not have it as it stands at present. I do not imagine he would have all those small auxiliary and wasteful motor-generators and reducers, and boosters and balancers. I am also of opinion that it is a great mistake to go in so heavily for accumulators. Mr. McMahon admits that the efficiency is decreased by their use, and also that the load-equalisation is only improved by about 10 per cent., but he falls back on their being useful as a standby. In the many instances in which I have tried to figure out an advantage for the storage battery, it has never worked out economically; it has always been more economical to put in the increased generator plant, although the difference in the capacity of plant requiring to be installed is very great. When you take into account the high cost of accumulators, the great depreciation (and this is far greater than is generally supposed), and the very low efficiency, this will generally be found to be the case. The efficiency of accumulators, as a matter of fact, may be anything you choose to make it, if you only buy an expensive enough one and run it at a low enough current density. In that respect the accumulator is just the opposite of almost all other electrical apparatus; its efficiency approaches 100 per cent. as the load approaches zero. In generators and motors, on the other hand, the efficiency is very low at light load. That is a striking and unique characteristic of accumulators. But capital expenditure and the depreciation on the heavy investment compel one to employ accumulators generally at as low as from 60 to 70 per cent. efficiency, if they are to be used at all, and the efficiency, of course, decreases with the deterioration of the accumulator. Mr. Hobart.

It also seems to me that the road would have been benefited by the use of 2,000 volts between outers—1,000 volts on the main generators and 1,000 volts on the motors, which could be of the single commutator type. Such a proposal would probably have been considered impracticable but a short time ago, but I am inclined to think that the tendency is now strongly in that direction. Engineers are rapidly finding out the almost insurmountable disadvantages of polyphase systems for railroading (except in so far as relates to generating plant, which for extensive lines may often with advantage be polyphase), and are going over to continuous-current systems. To increase the area of distribution, either from power-house or from sub-stations, 1,000-volt continuous-current generators are extremely practicable if driven at low speed. The design of the dynamo-electric machine, for small capacities, is generally more difficult the higher the voltage, but the most economical voltage increases with the capacity. For the generator capacities used in tramway work, and for slow speeds, 1,000 volts is decidedly within the economical limits. The generator requires fewer poles, which leads to lower losses in the shunt exciting spools, lower core loss, and lower commutator losses, both as regards friction and C^2R losses, because of the lesser current to be collected. As to the motors on the cars, 1,000-volt motors are eminently practicable, and with but a single commutator per motor. A

Mr. Hobart. standard railway motor, of which many thousands are at present in use all over the world, has been developed with a 1,000-volt winding, and has given excellent satisfaction in the factory, though it has not yet been tested on the road. The chief other consideration is in the controllers, where high voltage is probably a much less difficult consideration than high current capacity, especially in heavy work in train operation. In the tests of 1894, Mr. McMahon obtained the result of 69 watt-hours at the switchboard per ton-mile. The corresponding figure is not given in the 1903 tests; but I imagine Mr. McMahon has a pretty good idea of what it is, and I should be interested to know whether the increased amount of auxiliary apparatus and the accumulators have or have not increased the watt-hours at the power-house switchboard per ton-mile.

Mr. Bjornstad. Mr. J. Bjornstad : I would like to say a few words about the lifts, with which I have been concerned ever since the experimental one was supplied at Kennington. After some experimenting, that lift was made to work fairly satisfactorily, and stopped automatically at the floor level under varying loads. This was used to a great extent as a pattern for the new lifts on the Moorgate Street and Clapham extensions; but when those lifts were started, some difficulty was experienced in stopping them at the floor levels with varying loads. In his paper Mr. McMahon has put this down to the difference in the arrangement of the balance weights, but as the total weight of the balance weights is exactly the same in both cases, this cannot be the case. At Kennington the weight of the car, less a certain amount for the preponderance of the car, is balanced by separate weights, and the remainder of the weight attached to the driving ropes, while on the Moorgate Street and Clapham extensions all the balancing is done on the driving ropes. In both cases the total balance weight is equal to the weight of the car and half the load. The difficulty experienced in stopping the lifts when first started is, in my opinion, entirely due to the difference in speed, because at Kennington the lift runs at 120 feet a minute, while on the extension lifts the speed is 180 feet; the momentum of the moving parts is increased accordingly, and the difficulties in stopping about in the same ratio. These difficulties were, however, got over by the introduction of electric control.

Another matter referred to by the author is the wear of the ropes, which has taken place on the Moorgate Street and Clapham extensions. This wear is, in my opinion, entirely due to the small guide sheaves over which the ropes pass, and not to the driving gear. On account of the very limited space at these stations, it was necessary to keep down the size of the guide pulleys, most of them being about 3 feet in diameter, whilst the driving pulleys are about 4 ft. 6 in. I have examined some of the ropes which were taken off, and have found that that part of the ropes which had only passed over one of the guide pulleys at the top was just as bad as that part of the rope which had passed through the driving gear and over the two guide pulleys as well; I also found that the failure of the ropes was due not so much to wear as to the fatigue of the material, the wires having broken off without being worn down. These ropes, so far as I recollect, are on an average 2¾ in. circum-

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ference, that is, about $\frac{7}{8}$ in. diameter, and they are therefore well on the safe side of the 30 to 1 ratio, which is generally used, but which is apparently too small for this class of work. Wherever possible I would recommend a ratio of 60 to 1, and I think if that is done there should be no trouble from fatigue.

Some objection has been raised to the effect of the **S** drive, in causing the bending backwards and forwards of the rope, but I do not think that this effect should be considered by itself without also considering the size of the pulleys of the driving gear, because if one considers a system of pulleys, say 3 feet in diameter, and arranged so that a rope in passing over them is bent in one direction only, and a system of pulleys, say 6 feet in diameter, arranged so that the rope is being bent in opposite directions in passing over them, the total distortion of the rope or the strain on the outer wires will be practically the same in both cases. Therefore, if a rope will work satisfactorily when being bent in one direction over 3 feet diameter pulleys, it ought to work equally well when being bent in opposite directions over 6 feet diameter pulleys. In addition to this, I would like to point out that the idea of arranging the lead of ropes, whether for hauling purposes or for power-transmission, so that the ropes bend in one direction only, may appear very nice on paper, but in practice I do not think these expectations are fulfilled, because a rope, unless it is of very special make, will always twist a certain amount with a varying load. For example, if a rope during its passage backwards and forwards over a pulley, between two journeys, should rotate round its own axis 180°, it will be bent in opposite directions as in an **S** drive, and from my experience it is very difficult, without subjecting the rope to a stretching process, to prevent this and to make it run absolutely stationary, that is, not to rotate on its own axis. With transmission ropes, I have often found that they continually screw themselves along, unless they have been well stretched beforehand, and then twisted back three or four turns before being spliced. Further, with regard to the **S** drive, which is supposed to have a bad effect on the rope, I will refer to the ropes on the Islington extension where all the pulleys are 4 ft. 6 in. in diameter, with ropes $\frac{7}{8}$ in. in diameter. These ropes have now been at work for over two years, and I had an opportunity of seeing them a short time ago, when they appeared to be as good as new. I think that clearly shows that the **S** drive cannot have any bad effect on the ropes, when used with large diameter pulleys. Then with regard to rope renewals, in the old lifts, that is, the lifts on the Moorgate Street and Clapham extensions, the gears had to be placed at the bottom on account of insufficient head room; and this means that there is a very long length of rope to provide in the first instance as compared with the gear overhead. For example, on the 65 feet travel the ropes amount to about 340 feet in length with the gear placed below; while on the Islington extension on the same travel with the gear above they are only about 115 feet long, that is about one-third of the former; so that when the gear is arranged at the top the rope renewals, *i.e.*, the cost of new ropes, would amount to about one-third of the cost with the gears at

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the bottom; and the cost of taking the shorter ropes off and putting on the new would be very considerably less than one-third of the cost of the corresponding work of the longer ropes. Assuming, therefore, that the lifts on the Moorgate Street and Clapham extensions had been arranged with the gears at the top, the cost of rope renewals per car mile, as given by the author, would have been only one-third of the figure given, which would have compared favourably with the hydraulic lifts. This is on the assumption that the rate of wear had been the same as with the smaller guide pulleys, whilst if the gears had been arranged as on the Islington extension lifts, the wear would have been greatly reduced, and the cost of rope renewals might have worked out the same as on the Islington Extension, where the actual cost during more than two years working has been nil. In conclusion, I take the opportunity of expressing my great appreciation of Mr. McMahon's most interesting paper, and also of my gratitude to him personally for the assistance he rendered me during the construction of the lifts.

Mr. Highfield.

Mr. J. S. Highfield: I have had the privilege of knowing about Mr. McMahon's most interesting five-wire system of feeding a railway for some time, and I do not think it has been properly appreciated—at least, I have not met a great many men who have really taken the trouble to understand the extreme ingenuity of the system that Mr. McMahon uses on the City and South London Railway. He has told you, I think, that the system of feeding at 2,000 volts, that is to say, 1,000 volts above and below earth pressure, the third rail being earthed, through reducers, involves only the transformation of part of the total energy at each sub-station; but in addition to that the transformers, making a slight allowance for the inefficiency of the machines, can be approximately one-half of the capacity of motor generators or rotary converters with the ordinary system of alternating to direct current distribution, and therefore the cost is not very much more than half the cost of the ordinary sub-station plant. In addition there is the gain in efficiency. I should say it is questionable if there are many railways operating a sub-station with a higher efficiency than we have heard of—about 81 to 82 per cent.

Some remarks have been made to-night about the use of batteries in sub-stations. Now the advantage of a battery in the generating station is open to question. It is sometimes useful, it sometimes is not; but when it comes to using a battery in a sub-station, situated, it may be, five miles away from the generating station, the problem is somewhat different; because it must be remembered that in this case the battery capacity takes the place of its equivalent output of plant at the main generating station of high-tension feeders and of sub-station plant, so that the capital cost of the battery, if it were twice the cost of the steam plant, is still justified; because if the whole sum of the cost of generating plant, high-tension feeders, and rotary convertors is taken into account, the cost of the battery per kilowatt is generally very much less than that amount. Of course, if a battery is worked in such a way that its efficiency is only 60 per cent., then the repairs will be so extremely heavy that the battery is not warranted in any event,

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and unless you can get an efficiency of between 70 and 80 per cent., preferably nearer 80, it is no use putting in a battery at all. The depreciation of a properly handled battery is not in excess of the equivalent plant and feeders, and the advantage in working long feeders at constant current is worthy of consideration. The loss in a feeder handling a given number of kilowatts at constant current is less than the loss when the same number of kilowatt-hours is handled in the same time with varying current; the difference depends on the ratio between the mean current at which the energy is transmitted and the maximum current. For instance, supposing a given amount of energy is transmitted in a given time, and then twice the amount is transmitted in half the time, the amount of loss in that case will be twice what it was in the first case, and with any peaky load on a long feeder the loss is always greater than with the same amount of energy transmitted with a steady current, so that the increased efficiency in the feeding system should be allowed for when figuring out the possibility of employing batteries in a sub-station. In the tables at the end of the paper the author gives us the number of units handled down the feeders, but unfortunately he does not give us the whole number of units, and the probability is—I cannot say it is a fact—he will find that the units handled by the high-tension feeders, as measured at the sub-station, would be less when working with varying current than when working with constant current.

Prof. Carus-Wilson has raised a most interesting point as to the use of an earthed return for a railway system. I believe the reason why the insulated return is used on the Liverpool and Southport line, and the Mersey and other lines, is because under the Board of Trade regulations for drop pressure in the return conductor, namely, a maximum of 7 volts, it is cheaper to use the insulated return with a greater drop than 7 volts than it is to use an earthed return under the Board of Trade conditions. There cannot possibly be any advantage as regards safety in using an insulated return, as the negative rail is always earthed at one point, otherwise double-pole switching gear would be necessary on the trains, and complications too horrible to contemplate.

The costs given for the City and South London Railway are extremely good. A cost of ·44d. at the works is an excessively low figure. I note that the load factor is approximately 50 per cent. There are a good number of lighting stations working at this time of year with a similar figure, and it is interesting to note—I have noted it in my own case—that we can never obtain the same low costs that are obtained on the same load factor on tramway stations. It appears to me the reason is that the load should be evenly distributed over the whole of the twenty-four hours, in order to get a low cost. For instance, you can get a load factor of 50 per cent. in many ways. You can get a high peak at the ordinary time of maximum load on a lighting system, and a moderate load during the rest of twenty-four hours. Or you can get a series of peaks distributed through the day, and a series of low patches when the load is small, and it appears from railway experience that the load factor obtained in the latter way always gives you a

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chance of making better costs than in the former way. The reason is that the boilers work at a far better load factor under railway conditions than they do under lighting conditions, although the calculated load factor under the two conditions is exactly alike. It is very interesting to note the extremely level pressure curves that Mr. McMahon has shown. I should very much like to claim that as the result of the system of control that he uses in the sub-stations, but I believe the reason is that the engines are very well governed, and the generators are very carefully compounded, because even without a battery, the volts are exceedingly regular.

Mr. Shoolbred.

Mr. J. SHOOLBRED: Mr. McMahon's paper appears to me to contain many interesting points, but the one which is most instructive is the fact that, by the arrangement, he uses the continuous current only; he has entirely dispensed with the use of two different kinds of machinery, the alternating current and continuous current, as is the case in many generating stations, where the utilisation is on the continuous-current principle, while the transmission to a distance is on the alternating current one. I think it will be admitted by central station engineers, that the use of two different kinds of systems of machinery adds considerably to the complication of the working of the station. The three-wire arrangement which Mr. McMahon has introduced, and which, as Prof. Carus-Wilson says, is extremely ingenious, has been followed with considerable attention ever since Mr. McMahon himself described it some time ago in this room, when commencing to put it into operation. Mr. McMahon has practically solved the question of supplying transmission over moderate distances, such as would be required in most of our large boroughs for traction purposes, while for municipal electric lighting purposes it had previously been solved by Mr. Blackman at Poplar. For myself, I can only add, from my experience of the working of central stations, that this use of a single kind of machinery therein is a point of very considerable importance. There is another matter which is largely dwelt upon in the paper, namely, the use, in sub-stations, of storage batteries, and the interesting diagrams of the working which are given show what good results have been obtained thereby. Although it is nearly a dozen years since storage batteries were first used for lighting purposes, yet for traction purposes objections were for some time raised to their use. But those objections have been gradually disappearing; and the solution of the question arrived at by Mr. McMahon must add very considerably to the value of storage batteries. It appears to me therefore that Mr. McMahon's ingenious solution of both those points, as also of other matters touched upon in the paper, deserves our heartiest thanks.

The President.

The PRESIDENT: I think you will agree with me that this interesting subject will take more time for discussion than we have available to-night, so I think it would be well to adjourn.

The Four Hundredth Ordinary General Meeting of the Institution was held at the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, January 14, 1904—Mr. ROBERT KAYE GRAY, President, in the chair.

The minutes of the Ordinary General Meeting, held on December 17, 1903, were, by permission of the meeting, taken as read, and signed by the President.

The names of new candidates for election into the Institution were taken as read, and it was ordered that they should be suspended in the Library.

The following transfers were published as having been approved by the Council:—

From the class of Associate Members to that of Members—

J. Aitken.
Stanley Beeton.
Thomas Cooper.
A. G. Newington.
W. H. Whitehouse.
Ludwig H. Wilms.
William Wyld.
George A. Zeden.

From the class of Associates to that of Members—

George Balfour.
Leonard Newitt.
James Quick.
Adolph Schneider.
Edwin Cooper Wallis.
T. M. Winstanley Wallis.

From the class of Associates to that of Associate Members—

Joseph Ainscough.
James A. B. Horsley.
Emile G. Lind.
Arthur John Macphail.
Bernard Sankey.

From the class of Students to that of Associates—

John M. F. Wilson.

Messrs. W. W. Cook and O. C. Spurling were appointed scrutineers of the ballot for the election of new members.

Donations to the *Library* were announced as having been received since the last meeting from Messrs. A. S. E. Ackermann, Dr. H. Borns, E. Guarini, O. Linders, and Whittaker & Co.; to the *Building Fund* from Messrs. I. Braby, A. Burton, H. C. Channon, E. Coates, A. A. Crawford, B. P. Davies, W. H. St. A. Davies, R. A. Dawbarn, W. Duddell, J. H. Edwards, C. F. Farlow, S. Z. de Ferranti, S. E. Glen-

denning, S. S. Grant, R. Hammond, Lieut.-Col. Hassard, C. W. Hacking, Professor Hay, J. T. Haynes, F. C. Heritage, Capt. H. B. Jackson, G. F. R. Jacomb-Hood, J. Landstein, H. M. Lyons, W. McGeoch, junr., J. O. McLaren, J. C. M. Matthews, F. S. Miller, H. W. Miller, E. D. Morgan, J. T. Morris, H. E. Moul, C. W. J. Nelson, F. H. Nicholson, A. Nield, D. S. Paxton, E. Pink, C. W. D. Peel, W. G. T. Pope, W. J. Procter, R. O. Ritchie, W. M. Rolph, A. Rutherford, H. W. Sabine, P. W. Sankey, J. Shaw, M. Solomon, H. M. Stich, A. Stroh, Dr. Swan, A. A. C. Swinton, F. W. Topping, T. T. Tucker, J. C. Vaudrey, A. S. Wilson, and H. W. Young; and to the *Benevolent Fund* from Messrs. I. Braby, S. E. Britton, C. P. Cobb, A. Denny, G. J. Gibbs, H. J. Glynn, S. H. Holden, H. M. Lyons, W. McDonald, W. G. T. Pope, Sir D. Salomons, H. C. Silver, W. C. Smith, A. Stroh, and A. J. Stubbs, to all of whom the thanks of the meeting were duly accorded.

The PRESIDENT announced that, in accordance with the terms of the Willans Memorial Fund Trust, the Third Triennial Award of the Willans Premium, value £25, had been made by the Council to Mr. P. V. McMahon, Member, for the papers read by him on May 4, 1899: "Electric Locomotives in Practice and Tractive Resistance in Tunnels, with Notes on Electric Locomotive Design"; and on December 17, 1903, "The City and South London Railway: Working Results of the Three-Wire System applied to Traction, Etc."

The PRESIDENT: I have further to state that the Council has received a resolution of thanks from the Borough of Colchester for the picture which was presented at our last meeting.

The discussion on Mr. McMahon's paper "The City and South London Railway: Working Results of the Three-Wire System applied to Traction," etc., was then resumed.

The PRESIDENT: Before asking members to discuss Mr. McMahon's paper, if Professor Carus-Wilson is present, Mr. McMahon would like to ask him a question. Although Professor Carus-Wilson does not seem to be present, I shall ask Mr. McMahon to put his question, which will be communicated to Professor Carus-Wilson.

Mr. McMahon.

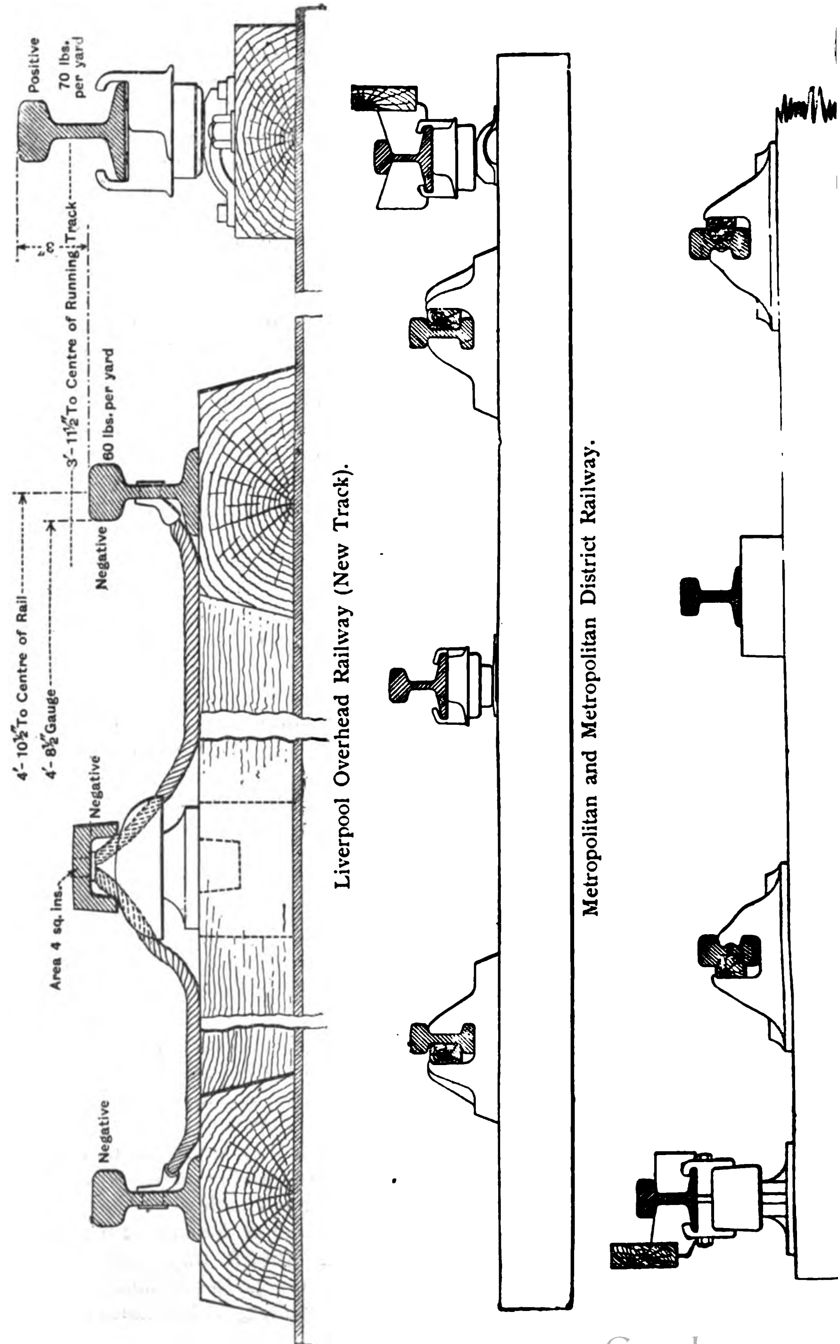
Mr. McMAHON: The point I wished to ask Professor Carus-Wilson was this: In his remarks he said that the three-wire system as in use on the City and South London Railway could only be applied where the rails were used as a return, and not where you had two insulated rails. I have thought over the matter, and I cannot see in what way he means that it is only applicable where the rails are used as a return. As far as I can see at present, the three-wire system and the method of changing from one side of the system to the other is equally easily applied to a case where you have an insulated return conductor.

Prof. Carus-Wilson.

Professor C. A. CARUS-WILSON (*communicated*): In reply to Mr. McMahon's question as to why, in my opinion, the three-wire system could not be used unless the track rails were used as a return, I would point out that if all the conductor rails are insulated, a ground on either of the outers means that the other outer is at a thousand volts from earth potential. I should consider this an intolerable possibility: it can only be avoided by grounding the return.

Mr. T. STEVENS: I would like to ask the author a question or two, if I may, on some of the details of the paper. He tells us that his "circuit-breakers do not entirely break circuit, but that he has a resistance in parallel" with them. He says, "All the circuit-breakers, both generator and feeder, with the exception of the high-tension feeders, are similarly arranged." On the author's diagrams he does not show all these circuit-breakers with resistances shunting them. It appears to me that if he did have a resistance shunting each circuit breaker, he would have a condition electrically similar to that in the Paris Metropolitan at the time of the fire. There they had the section insulators in the third rail bridged, and at each feeding point a 4,000 ampere circuit-breaker was connected, so that it was possible, I believe, to let at least 8,000 amperes flow into a fault midway between two stations without the circuit-breakers acting. I take it that Mr. McMahon's second circuit-breaker, shown without a resistance in parallel, is set somewhat higher than the first, and if a persistent short circuit comes on, the second one acts, and prevents any continuous flow of current. The report of the Committee which has investigated the Paris Metropolitan accident has recently been published, and no doubt every one has seen these recommendations. That "the driver shall be able to lift the shoe from its position in the cab" is certainly based upon Mr. McMahon's practice. They also recommend that the third rail should be divided into sections, each protected by an overload cut-out. This has now been done on the Paris Metropolitan system. Another suggestion of the Committee on the Paris Metropolitan accident is that between stations they shall have switches to cut off the current without the necessity of telephoning. A switch intended for short-circuiting purposes only must have liberal proportions. It is very desirable to be able to short-circuit your third rail to be certain that it is "dead," if you desire the passengers to *walk* through the tunnel. They also suggest in the Report that provision should be made for cooling the motors whilst running in service. I do not like the addition of blowing machinery to the other apparatus that we have to put into trains. It is satisfactory, with present requirements as to power, to put in a motor which will not overheat without such special cooling. Professor Carus-Wilson raised, at the last meeting, the point that it was better to have two insulated rails than a single one. The following week the papers published a report of a death in South Africa, which, although occurring on a tramway system, is a parallel case to what was recommended. A gentleman, stepping into his bath, completed a circuit between the water supply from a shower and a drain pipe which went to earth, and it killed him. That shower was in contact with an insulated (that is, not "earthed") trolley standard, and the defective insulator on that standard made the water-supply pipe alive, so that there was one fault waiting for a second fault to produce a short circuit. That second fault came through a human being. To avoid risking lives, I consider it of the utmost importance, wherever possible, to have one side earthed. In the 5,000-volt Central London Railway circuit, the centre of the star winding at Shepherd's

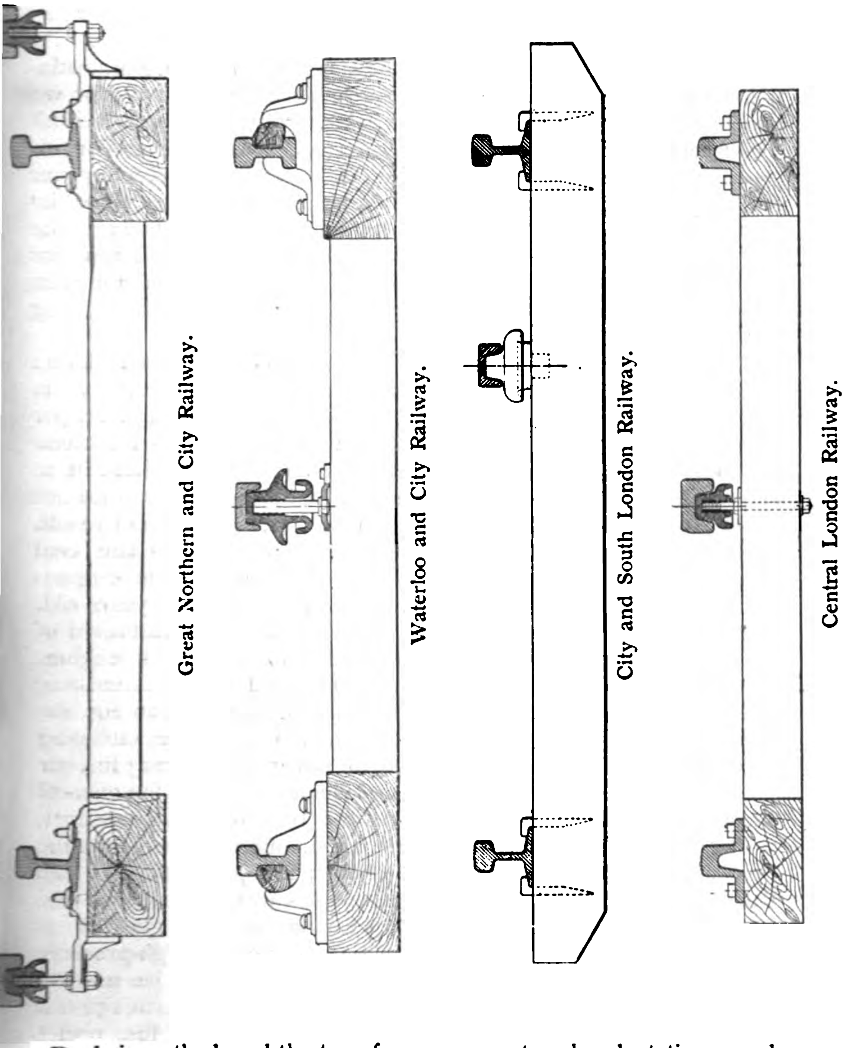
Mr. Stevens.



Liverpool Overhead Railway (New Track).

Metropolitan and Metropolitan District Railway.

Mr. Stevens.



Bush is earthed, and the transformer cases at each sub-station are also earthed by direct connection to rails and tunnel lining. This of course incidentally gives us a lower possible voltage to earth, but it ensures the breakdown of the system when *one* fault appears. That is not advantageous to the system, but it is a precaution against accident to human beings, and we cannot do too much in this direction. It was also suggested that the cables under the cars are the most dangerous part of the equipment. We can build up our motor in an iron compartment, as they are built on the Central London Railway, for instance, but to pass cross-over roads we must connect two shoes,

Mr. Stevens. which bridge that gap, by a cable under the bottom of the car. I have never heard of an accident due to such cables, and I should like to ask Professor Carus-Wilson if he has ever heard of such an accident. At the same time, the nearer we get to the Board of Trade recommendations on this subject the nearer we approach the ideal. No doubt we all remember that the suggestion which Mr. Trotter made was that all such "connections should be rigid: they can be bare, or enamelled, or protected by non-combustible ferrules inside iron pipes, and wherever flexibility is essential it is to be provided by pinned hinges or knuckle-joints." I have also put up another diagram (pp. 172, 173) showing the positions of various conductor rails in England. Mr. McMahon has always used that type of conductor-rail which gives the simplest and best mechanical design, the greatest freedom from sparking and the lowest capital cost.

Mr. Booth. Mr. W. H. Booth: I should like to make one or two remarks on the steam side of the question. I think I am allowed to do that by the "etc." of Mr. McMahon's title. I notice that the coal consumption per unit is given as 3½ lbs. That, I take it, is a good result in an electrical station, and for that reason I have taken hold of it to criticise it to some extent. Three and a half pounds of coal per kilowatt would not have been looked upon twenty years ago as a particularly good result. I am quite aware of the effect of load-factors in raising the coal consumption, but I should like to call attention to some engines familiar to me twenty years ago which were then thirty years old. They were those old-fashioned engines, which, we are accustomed to say, revolved occasionally. There were two horizontal engines exhausting into two beam engines, and two vertical engines exhausting into two marine engines, and the actual coal consumption for the month of September, which was the best month of the year, including all the coal used for mill warming and for sizing, came to 2·23 lbs. per I.H.P. If you multiply that by 1·33, and divide by 0·85 for the over-all efficiency, assuming that these engines had been driving generators, you would have exactly the same coal consumption as you get in the City and South London to-day, namely, 3·5 lbs. per kilowatt. The steam pressure of those old-fashioned engines was 60 lbs., while the steam pressure on the City and South London is about 150 lbs. It seems to me there is not sufficient obtained out of the high-pressure steam that we use at the present day compared with what we used to get years ago, in spite of the too numerous cylinders. Steam at 150 lbs. has a density something like double that of steam at 60 lbs., and I think the denser steam carries considerably more water than steam of lighter density would carry. I notice on p. 134 that the steam used on the City and South London Railway was tested by a Carpenter calorimeter, and showed 4·5 per cent. of wetness. I do not believe that any man can take a true sample of steam out of a pipe. I believe that if you get a sample you can test it and find the dryness, but I am confident that no man knows what is inside a pipe, or that he can get out of it a true sample of steam. In all papers you see this item of the wetness factor of steam, and yet we know absolutely nothing about it. We cannot tell whether, on the City and South London, the wetness is

4·5 or whether it is 14·5; it entirely depends upon how you take your sample from the pipe; and when you have got your sample you do not know that you have got a true one. There is no way of telling how wet steam is, but there is a way of telling how dry steam is—if steam is dry. If you superheat steam only 5 degrees, you can test it with a thermometer, and you know it is dry. You know that it is hotter than the steam in the boiler, so that any superheated steam can be tested at once by means of that simple instrument, the thermometer. Mr. Booth.

The author has told us that his stokers found out that the Willans engine was not so economical as the Corliss engine. I do not wish to say anything against the Willans engine or against any high-speed engine, but it does seem to me that unless you use superheated steam with these high-speed engines they are not going to do you very much good. It hardly seems fair to compare a high-speed engine using wet steam with a slow-speed engine which has a much better drainage. The interior surfaces also of a high-speed engine are enormous, especially if there is a central valve. It may be treble what the minimum should be. If you use an engine with very large internal surfaces, and you use wet steam in that, you are bound to get waste. You may get a proportion of the initial steam condensed up to 40 per cent. I made a trial a few days ago of measuring steam volumes on the diagram. Using ordinary saturated steam, I found there was 40 per cent. more steam on the low-pressure diagram just before the exhaust point than there was in the high-pressure cylinder at the cut-off. I do not think that that was due in any sense to leakage past the valve, but was simply due to condensation and re-evaporation in the cylinder. That would not occur, or it would not occur to the same extent, if the steam was thoroughly dry to begin with. We have heard a good deal in this room about the question of entropy. I suppose there is not one in ten of us who understands anything about entropy: engineers to-day have not time to study it, and if they do understand it they have not time to work it out. I should like to point out that steam engines for the last hundred years have been drawing us diagrams from which we can measure the wetness of the steam. Now thermo-dynamics have nothing whatever to do with the steam engine as we find it. If we had a steam engine which had adiabatic cylinders we should be able to do some good with the theory on the thermo-dynamic basis: but we do not get adiabatic cylinders; they are not known, and therefore why trouble ourselves with thermo-dynamics when we have the practical question before us? Until we get steam dry throughout the whole range, which is practically impossible, it is useless to argue the question on a thermo-dynamic basis. Mr. Sayers has kindly given me some figures relative to the Maybank power-station in Staffordshire, which I think would be interesting to the meeting. The coal consumption was 4·37 lbs. of local pea coal per kilowatt, the cost 0·195d.; the oil, water, and engine-room stores amount to 0·0203d.; repairs and maintenance to 0·0277d.; salaries, or running wages, 0·1377d.; giving a total cost per unit of 0·3807d. That, I think, is an exceedingly good result, considering that the weight of coal used is 4·37 lbs. It was, of course, much cheaper per ton than what Mr.

Mr. Booth. McMahon is using, and the weight per kilowatt is but another example of the excessive coal consumption of electric stations due largely to excessive steam wetness.

Mr. Jones. Mr. HERBERT JONES: It seems a very great drawback that the generating station at Stockwell is so situated that all coal and stores have to be carted into the works. The cartage is something like 15,000 tons of coal per annum, and must be a very heavy item of expenditure.

Mr. McMahon states that an all-round satisfactory water-meter was not to be found that would work with hot water under boiler pressure. Why was it necessary to have a water-meter that would work under boiler pressure? There are meters which will work in a quite satisfactory manner in the suction of the feed-pumps. For instance, on the Waterloo and City Railway we have had a Kennedy water-meter working for the last five years. It has been checked over and over again, and always found to be within 1 per cent.

Mr. McMahon apparently does not favour motor-driven pumps for condensing and boiler feed purposes. He has not used them extensively. From my own experience I think there is economy to be obtained from using motor-driven pumps, with of course a steam pump as a stand-by for boiler feed purposes.

I have had considerable experience of working an electric railway, both with and without a resistance connected across the circuit-breakers on the switchboard, and am convinced that it is safer to break the circuit completely. From the generating station point of view, however, there are advantages in the system Mr. McMahon has adopted. On the other hand, if you consider the case of a feeder going to earth, the circuit-breaker opens, throwing a resistance into the circuit, and the fault is still fed with a large current which does a great deal more damage than if the circuit were completely broken.

I should like to ask Mr. McMahon how the flexible bonds mentioned are fixed to the bottom flange of rail. I have carried out some tests on rail bonding, and find that the greatest loss is at the contact between the rail and the terminal of the bond, so that the important point is to have the track well riveted. On the Waterloo and City Railway this is done by means of a hydraulic riveter, and each rivet is closed with a pressure of 40 tons. We have been running for five and a half years, and have never yet found a slack rivet.

The cost per unit and other figures given towards the end of the paper are certainly low, but the following figures for the Waterloo and City Railway are perhaps equally good when the number of units generated and load factors are taken into consideration (see p. 177).

It will be noticed that the number of units generated at Waterloo is less than one-seventh of the City and South London figure; also the load variations at Stockwell do not appear to exceed 25 per cent. on either side of the mean: the corresponding figure for the Waterloo and City is 75 per cent. In fact, the output frequently varies from 150 to 1,050 amperes in under 30 seconds. In spite of this the variation of 'bus-bar voltage does not exceed 4 per cent, a result due mainly to the excellent governing of the high-speed "Belliss" engines. The Waterloo

Mr. Jones.

	C. & S. L. Railway, Half-year ending June, 1902.	W. & C. Railway, Half-year ending December, 1903.
Units generated	3,781,087	499,234
Coal	0·310	0·532
Water, oil, and other stores	0·046	0·042
Wages	0·056	0·306
Repairs and maintenance	0·028	0·118
Total works cost	0·440	0·998
Distribution	0·035	Nil
	0·475	0·998
Coal per unit, including all losses ...	3·9 lbs.	5·6 lbs.
Coal per ton-mile (at the switchboard)	0·237 lb.	0·313 lb.

and City cost per unit for water, oil, waste, and other stores is lowest, probably due to high-speed enclosed engines using less oil than slow-speed. The units per ton-mile are given by Mr. McMahon as 0·0552 on the locomotives, and from other figures he has given this comes out at 0·0608 at the switchboard. The units per ton-mile on the Waterloo and City are 0·0552 at the switchboard, or roughly 10 per cent. lower than Mr. McMahon's figure, a result due in some measure to distance between stations being 1½ miles on the Waterloo and City line.

Mr. McMahon states that the percentage of time lost by the locomotives through armature failures comes out at 0·16 per cent. The record of the Waterloo and City line, using motor trains, is much better than that. The time lost, for instance, over the whole of last year in breakdowns and delays from all causes is 0·135 per cent., and from electrical failures of every kind the figure is only 0·053 per cent., or less than three minutes' delay to traffic per week, averaged over fifty-two weeks.

The last figures Mr. McMahon gives are in pence per train-mile; if these are converted to pence per ton-mile, the total cost figure would come out at about 0·10 penny, the weight of the City and South London Railway train being something like 46 tons. The Waterloo and City of course come out higher at 0·16d. per ton-mile. The figures given look remarkably good until you take into consideration the very light train.

Mr. Clark.

Mr. E. V. Clark: I think the remarks that Mr. Booth made a few minutes ago concerning the effect of superheat in steam upon high-speed engines perhaps account for one series of figures in the paper, and that is the difference in the results of the comparative tests of the

Mr. Clark. Corliss and Willans engines on their guarantee tests, when no doubt care was taken that the steam was properly dried and everything satisfactory, and on the three-hour tests under working conditions. If you consider the tests of the engines on their guarantee trials (pp. 134, 135), and make allowance for the fact that the Willans engine was running with 23¼ in. of vacuum, and the Corliss engine with 25¾ in. vacuum, you will find that really the increased economy of the Corliss engine is only measured by a very few per cent. over that of the Willans. If, on the other hand, you consider the three-hour tests—and that is a much more trustworthy guide as to their steam consumption in daily use—you will find that the economy of the Corliss engine is 20 per cent. better than that of the Willans engine—a very different figure. But I think, if the author will excuse me saying so, he has phrased the description of these tests in such a manner as to make the Willans engine appear in a rather worse light than is really the case in comparison with the Corliss. He states, on page 137 of the paper: "During the test of the Willans sets the average load on the 125-kilowatt sets was about full normal load, while the 300-k.w. sets also were up to full normal load, *i.e.*, 600 amperes each. The average load of the Corliss sets during the test was 900 amperes each, or about 56 per cent. of normal full load." Now the specification of the Corliss engine given in the earlier part of the paper shows that it was designed to have a most economical normal working load of 600 k.w., giving 800 k.w. as overload at late cut-off; and the tests given at the top of page 135 show that this Corliss engine is most economical at the load for which it was designed—600 k.w. On the other hand, the Willans engines, which were designed to be the most economical at 320 k.w., were required to work up to 400 k.w. without pulling up; and as their governing is on the throttle, it follows that they are most economical at the overload of 400 k.w.—in fact, as shown by the tests, 7½ per cent. better at this load than at 300 k.w.—and no doubt the 125-k.w. sets would similarly be most economical at their stipulated overload. Therefore I think it is expressing things in a fairer light to say that both the Willans engines and the Corliss engines at the time of their tests were working at 75 per cent. of their most economical load. No doubt the fact that the Corliss engine is governed on the expansion valve makes it more suitable for traction purposes. In a lighting station, where at times of heavy load a considerable overload may be obtained by admitting high-pressure steam into the low-pressure cylinder, the Willans engine may be designed to work for a great part of its time (that is to say, if the station is of reasonable size) at its most economical point. I think it would be of great benefit if the author would state in these three-hour tests what were the boiler pressure and vacuum on the average in the two cases. Presumably from the paper they were similar, but there is nothing definite saying so, and it is just as well to have this information so that there can be no doubt that these figures, 30·2 lbs. for the Willans and 23·8 lbs. for the Corliss sets, are under similar working conditions. Referring to the all-day tests, April 8, 1903, I also venture to ask the author if he would allow us to know something as to the engines running at various hours of the day, since I see the steam per unit, includ-

ing condenser (but excluding the hydraulic engines, no doubt) was 23·88 lbs. per unit, which is practically the same as was obtained on the Corliss engine in the special three-hour test. If the Willans engines with their higher consumption were running for much of that day, it certainly seems to show that the Corliss engines must have been working very much better indeed than is indicated by the figures for the three-hour test. I suppose that the units generated on that trial were measured on to the 500 volts positive and negative 'bus-bars, and that the current required for the high-tension feeders was obtained through motor generators, no allowance being made for this in the figures given. There is nothing to say so in the paper, but apparently that is the case, and of course it makes an appreciable difference if but two engines are running and the 125-k.w. sets are out of use. Mr. Clark.

With regard to the electric and hydraulic lifts, the figures of working costs for the two on page 142 are very suggestive; but I have looked in vain in the paper for information enabling me to tell how much capital charges should be debited to the hydraulic and to the electric lifts. If those are added, I think the electric lift will come out in a much poorer light than in these figures, as it is probably pretty well known that in the Central London Railway extension at the Shepherd's Bush Station they have now added hydraulic lifts, although the original lifts are electric, putting down two electrically driven pumps to supply the pressure-water.

The author mentions in the early part of the paper that it might be considered advisable by some that, instead of having so many engines in his station, he should have a few large sets, say generating 1,000 volts across the outers; but, as he points out, that would not have answered. I should be glad to know, however, if there were any reasons why two generators, or one double-wound generator, should not have been put on the one engine shaft. For instance, if the 800-k.w. Corliss-driven generators had been double-wound, having two commutators and generating 500 volts on each side, it seems to me it would have simplified the plant in the station a very great deal. At the present time, whenever the high-tension feeders are in use, it means four generators running in the station, either steam-driven or motor-driven, and that certainly looks somewhat extravagant. If double-wound armatures were used on the 800-k.w. sets, it would not mean any great complication on the switchboard. Each machine would require one three-pole double-throw switch, the two windings being permanently in series; and the double-throw switch in one position would place the machine between the 500-volt positive, neutral, and 500-volt negative 'bus-bars, and in the second position between the high-tension, low-tension, and neutral 'bus-bars, one machine being capable of being put on the positive and the other on the negative side of the system, this giving quite sufficient change-over arrangements. Certainly there are various points to be considered in this case; for instance, the compounding of the machines would have to be taken partly from each commutator; then the equalising switches would have to be carefully thought out to make sure that the machines would run satisfactorily in parallel; and the compounding of the machines would not be as good as at present. But the advantage of having but two or

Mr. Clark. three sets running instead of the four needed at present would be well worth the extra trouble and expense caused by the machines being double wound.

I think it is a pity that so little has been said as to the one point which prevents any general adoption of a three-wire system for surface tramways. That, of course, is the difficulty of balancing and the consequent question of rail-drop. The Board of Trade limit of 7 volts in the negative rail return is quite hard enough to keep within in ordinary working, and the Board of Trade specially stipulate that the trolley line must be connected to the positive terminal of the dynamo, and the rail return to the negative. If any one proposed to use the trolley line as the negative and the rail as the positive, I think the Board of Trade would probably limit him to 2 or 3 volts drop in the rail return, since in those circumstances there would be much more danger from electrolysis ; and in a three-wire system, however perfect the balancing is normally, there is bound to be at times a heavy positive current in the rail. Then the Board of Trade specially state that at no point must there be a difference of more than 4½ volts between the rail and adjacent pipes if the rail is positive to the pipes, or more than 1½ volts, only one-third of the amount, if the rail is negative to the pipes, and that, again, would be a great difficulty in trying to use the three-wire system under ordinary methods. Mr. McMahon is doubtless free from trouble on this point, since his tube is metal-sheathed, and he is away down below all pipes, except his own hydraulic pipes ; but I should very much like to know if, when he was designing his line to work on the three-wire system, he had any trouble with the Board of Trade in getting their approval. I do not know whether his railway is under the ordinary Board of Trade regulations, but it appears that one can only work a tramway upon the three-wire system by obtaining special permission, as this method is not contemplated under the ordinary regulations. It seems that perhaps Mr. McMahon has hit on the idea which will allow of three-wire tramway working, and that is the use of battery sub-stations, with a Highfield automatic booster to take charge of the peaks of the load. It is the momentary peaks of the load which are the trouble of tramway working, as the normal rail-drop may be calculated and kept within limits. By having several battery sub-stations, perhaps scattered rather frequently on the line, it should be quite possible to keep well within even the 3-volt drop when the neutral is acting as the positive wire. One would adjust one's system so as to have a drop of a couple of volts negative at times of heaviest normal working, and that would allow a variation of 4 volts up or down when the peaks were first on one side and then on the other, the batteries being relied on to keep the peaks within this limit. One thing that comes out from Mr. McMahon's curves, however, is that the Highfield reversible booster does not seem able to keep pace with the peaks of the load. If the curves of the Angel sub-station output are examined, it will be seen that the variations of the motor and generator currents are much more rapid than that of the battery discharge. The battery current appears in general as a smooth curve, though very undulating, one minute discharging, and a couple of minutes later

charging again; but it has not got the very rapid serrations of the motor and generator load. I fancy the Highfield boosters Mr. McMahon uses were some of the earliest constructed; and possibly they can be made now to follow up the fluctuations more rapidly, for from the curves given there is plenty of scope for improvement in this respect, though no doubt they do a great deal at present towards steadying the load. Mr. Clark.

Mr. McMahon referred to the remarks of Professor Carus-Wilson at the last meeting as to the impossibility of the use of a three-wire system with entirely insulated return. It seems to me that the objection to that system is that, supposing an earth should be developing on the negative rail, it will at once create a difference of potential of 1,000 volts between the positive rail and the earthed parts of the car, and that might, of course, cause considerable trouble to the controllers and to the motors, unless they were specially designed to be able to withstand 1,000 volts between their working parts and earth, although only 500 volts crossed the terminals. But this surely is not a matter which need absolutely prevent the use of the three-wire system with the insulated neutral, since it is merely a question of insulation, and of satisfying the Board of Trade that the gear is safe to handle.

Mr. H. M. SAYERS: It is only right that I should express my very great admiration for Mr. MacMahon's ingenuity, and the obligation we are all under to him for showing what can be done with low-tension generators and with low-tension continuous current distribution for railway purposes. Mr. McMahon has thoroughly grasped the notion that economy of distribution and economy of generation have to be considered together, and that to get the lowest possible cost of current at the train is an object which must not be kept out of sight. It is of no use to put down a station in the best possible place for generating, and to keep down the generating costs to a minimum, and then to have to use, on account of the position of the station, a transformer system, which means a constant loss of 10 or 15 per cent. of the power generated. Mr. McMahon has succeeded in getting something like 90 per cent. of his generated power to his locomotive, and in doing that he has beaten, as far as I know, every three-phase system which is at present in use, both as regards overall economy and cost of power delivered to his locomotive, and shown that this can be done by the provision of a low-tension station at every ten or eleven miles along a line. Of course every case must be considered on its own merits. There are cases in which there is no doubt Mr. McMahon's system will prove to be the best; there are other cases in which it will not; but at any rate he has shown, as no one else has shown, what can be done with the simple 500 volts and a three-wire system. I also wish to refer very briefly to Professor Carus-Wilson's remarks about the middle rail. I understand that his objection to the rail return arrangement is that it is earthed, and consequently that any leakage on a car becomes, or may very quickly become, a short circuit. I think Professor Carus-Wilson is looking at one danger and rather overlooking another. It will be within the recollection of many people here that early experience with alternate-current transformer systems showed that it was very desirable Mr. Sayers.

Mr. Sayers indeed to make sure of the exact difference of potential between any part of the system and earth, and that necessity, and some very sad lessons which arose from the overlooking of that necessity, led to the use of concentric cables with the outer earthed. We had then always one dangerous terminal everywhere, and we knew which was the dangerous terminal; we had a safe terminal everywhere, and we knew what we could do with it. That was a condition of safety of very great use as regards the protection of human life from shock dangers, and I think that condition obtains on a railway as well as on lighting systems. It may be that the railway conductors are not quite so accessible to persons as lighting wires; but there is the fact that if you have a wire, which is sometimes at earth potential, and sometimes 500 volts above earth, that very uncertainty constitutes a danger. It is not necessary that the leaky wire shall be dead earthed; it is quite possible, every one knows, to get a dangerous current through a comparatively high leakage resistance. It seems to me that there is no difficulty in arranging for the middle rail, in such a system as Mr. McMahon's, to be insulated throughout the course of the line and to be earthed at the generating station; but the earthing at the generating station may, in a well-known way, be made to afford a test of the insulation of each side of the system. It is well known that the negative conductor tends to take earth potential because it becomes leaky. If you do not earth the middle wire it is practically certain that you will get your positive conductor 1,000 volts above earth and your negative conductor at earth potential very soon, and under those conditions the positive conductor is a dangerous conductor. It is dangerous to human life; it is dangerous to some extent to the motors. It seems to me very much better to earth the middle wire under such definite conditions that it affords an insulation test of the rest of the circuit, and keeps the pressure distributed in a perfectly known manner.

Mr. Brown. Mr. J. W. Brown: I should like to make a few remarks on the question of lifts. It has been my good fortune to be associated with hydraulic lifts and electric lifts, and therefore the few remarks I have to make may, I think, be taken as quite unbiassed. In the early days of electric lifts we had considerable trouble with them, but we have arrived now at a fairly satisfactory electric lift. Mr. McMahon, in comparing electric with hydraulic lifts, states that the first cost of the electric lift can be favourably compared with that of the hydraulic. That is so if you take a travel of something like 160 or 170 feet. Below that, the hydraulic lift is cheaper; above, the electric lift is cheaper. In the case of the Central London Railway the estimates for hydraulic lifts came out considerably less than the estimates for electric lifts. This was without including the cost of the pressure main from Shepherd's Bush to the Bank and the exhaust main from the Bank to Shepherd's Bush, which quite outweighed the difference between the hydraulic lifts and the electric lifts themselves. In the case of the New Brighton Tower lifts, with a travel of over 300 feet, the electric lifts were considerably cheaper than the hydraulic as estimated. Mr. McMahon has made a slight error in that statement. I think he has

been comparing estimates obtained from Messrs. Armstrong thirteen years ago for hydraulic lifts with the prices obtained from manufacturers now for electric lifts. The next point I wish to refer to is the rope renewals. The contractors were considerably hampered by the small amount of head room above the lifts; consequently the guide sheaves were very small; some of them only 3 in. diameter. This for a 1 inch rope is very small, although many text-books say that the diameter of the sheave should be about thirty times the diameter of the rope. In that case you do not get sufficient life out of a rope. Mr. McMahon is in the fortunate position, with regard to his hydraulic lifts, of having sheaves 5 feet in diameter; the result is that the life of the hydraulic lift ropes is some 7 or 8 years, but with the electric lifts and their 3 feet diameter sheaves you cannot expect to get the same length of life. Mr. Bjornstad at the last meeting said he thought that the S drive did not affect the life of the rope. With that I cannot agree, because there is no doubt that twisting the rope around the S drive and alternately putting the wires in extension and compression must lessen the length of the life of the rope. With regard to the conditions which an ideal lift for "Tube" railways should fulfil, the first is that the lift should start off and attain its maximum speed quickly, and on arrival at the top or bottom level shut off automatically. That condition the hydraulic lift fulfils perfectly, but the electric does not. The latter can be started and got up to maximum speed quickly, but cannot be stopped so easily as the hydraulic. You have a brake; you have the unknown quantity of the lift attendant and you have a variable load—a combination which prevents the electric lift from being brought to the floor level so readily. On the other hand, the low cost of working the electric lift is very much better, as proved by the figures which Mr. McMahon has given in his paper. These figures, however, I believe might be very much improved as regards the electric lifts. Perhaps we may have a system combining the advantages of both the hydraulic lift and the electric lift; if that is done I think we shall get a nearly perfect lift. Mr. Brown.

Mr. W. H. PATCHELL: I think we must all feel very much indebted to Mr. McMahon for his excellent second chapter to the paper which he read five years ago, but I am sure a great many members, like myself, are extremely disappointed that Mr. Mark Robinson was unavoidably prevented from attending this evening. Where Mr. McMahon comes from, it is almost common courtesy if a man trails his coat to tread on it, and I certainly came here expecting to see a good fight! My experience is rather in accord with Mr. McMahon's as regards engines. But I do not think he quite told us the whole tale. He rather leads us to believe that as regards low-speed and high-speed engines it is purely a question of speed. Now, a great many other factors come in. A very important factor, in my experience, is the number of cylinders. I have proved to the satisfaction of my shareholders that we can handle any load that comes on to us more cheaply on a three-cylinder triple expansion 1,500 H.P. engine than we can on three 3-crank—that is, six-cylinder—500 H.P. compound engines. We can take any load that comes on to that one unit and run through a day Mr. Patchell.

Mr. Patchell. on less coal than we could by chopping and changing about between two and three engines, although the total plant would be the same. You may say it is a question of compound *versus* triple, but it is not. In another works with which I am connected—the particulars of which I have been too busy to bring before the Institution, but I hope to one day—we have had some triple engines of 1,500 H.P. and other engines of 2,500 H.P. The 1,500 H.P. engines run at 230 revolutions per minute, the 2,500 H.P. run at 84; and the stokers have found out what Mr. McMahon's have found out—that they can take any load that comes on more easily with the 2,500 H.P. than they can if the 1,500 H.P. engines are running. There the question of the number of cylinders and also the question of the type of valves come in. I think a great deal too much importance is attached to small cylinders. People tell you that if you get small cylinders you can examine and repair them more rapidly if necessary. If they are vertical tandem you have one cylinder under the other, and you have to strip the high pressure to get at the low, and that loses time. Then, again, if you take, say, 9-in. cylinders and a 13-in., you can strip one 13-in. much more quickly than you can two 9's, although they are equal in area; and you will find that you have less bolts on the one 13 than on two 9's, so that I think too much importance is attached to that point. With regard to the question of steam, there is a very great deal in what Mr. Booth has told us. When I said in this room, I think in 1896, before the Mechanical Engineers, that superheated steam was better than saturated, even though it was reduced again to the temperature of saturated steam, some people laughed at me! They told me I was like the Duke of York, who took his men up a hill and brought them down again! But I have found it true over and over again, and I believe it is solely due to the fact that Mr. Booth put before us, that the superheated steam, although it has lost its superheat, has less water in it than saturated steam of the same temperature. If you want thoroughly to deceive yourself, go in for steam calorimetry; you cannot get the same results two days running! If you put two men on to take samples from the same pipe, they will give you two different results. If you try two calorimeters and two men, then you may get four results! The only way of telling that you have dry steam is to put a thermometer into it, and make sure it is superheated. As regards steam pipes, I see by the diagram that Mr. McMahon has got a most excellent condenser in his engine room! He has a double ring of steam pipes. If he will run for a day with the ring on, and then another day with one half shut off, I can promise him he will find a very great difference. I see that not only has he a double ring, but he has the luxury of double stop valves on his boilers. If he would put that money into a proper condenser plant on the exhaust side of his engines he might get results which we are told the turbines give. At the same time we must congratulate him warmly on the comparison of his results in 1903 with his results in 1894—an improvement to practically a third of his former coal consumption. I think we have also to consider this Paper with the knowledge of what the author has had to contend with; he could not burn his whole plant down and start

afresh; he had simply to go on improving and adding to it as opportunity arose. I was in Mr. McMahon's station in the very early days, and I remember that some of his gear would be now practically little better than an object lesson in what to avoid—the jockey pulleys particularly, they are abominable things. Mr. McMahon mentions the question of the joints on the steam mains blowing out. I think people ought to have joints now that do not blow out, because we can get such joints. I do not know whether he is still using insertion joints, but a metal to metal joint or a corrugated ring will not blow out. It is not now necessary to have a double steam ring with its inherent defects, simply because you are afraid of a joint blowing out. I think Mr. Hobart mentioned at the last meeting that he hoped people would go in for thousand-volt motors. I have not had a thousand-volt motor on tramcars, but I have been running forty 200 H.P. motors on 1,000 volts for several years past, and the breakdowns have been practically nothing; I do not suppose we have had half a dozen burnt-out armatures in that time. In traction work you would have to put the voltage on the field that you had on the armature, but if we can get them to work for fixed motors I think there is every hope of the voltage being raised considerably, and safely raised, for traction work; and of course on work in tunnels you do not have the defects and risks which might confront those who are undertaking street work. With regard to the balancers, I do not gather whether he has the fields crossed or whether they are compounded. When first I tried balancing on the three-wire with an ordinary double balancer I thought of having the fields crossed, and then Messrs. Siemens asked me to try some compound turns. We tried both ways, and there is really very little in it. Mr. Patchell.

Mr. E. J. Fox: I am sorry that Mr. Mark Robinson, who had a good deal to say on the steam side of the paper, has been obliged to go out of town unexpectedly; he had hoped to be here, and to join in the discussion on Mr. McMahon's interesting paper. I should like to make a few remarks on the table of generating costs given on page 154. Mr. McMahon was good enough to send me some weeks ago the details of his costs, which I have compared with a few other installations working under somewhat similar conditions of good load factor, and I should like to give you some of those figures. Mr. McMahon's coal consumption per kilowatt, taken over six months, comes out at 3·9 lbs. per kilowatt, practically 4 lbs. I find there is very little difficulty in getting, under rather more favourable conditions than prevail at Stockwell, down to $2\frac{3}{4}$ lbs. to $3\frac{1}{2}$ lbs. of small coal, costing about 5s. a ton at the pit mouth. In one case, for instance, we get down to 2·8 lbs. with rather a bad week-end load, which I take to be equivalent to about 2·7 lbs. if the load over the week-end had been maintained at the normal load, or cut off altogether. In another case, averaging over a month, the figure comes out at $3\frac{1}{10}$ lbs. of coal per k.w. on the switchboard, coal costing 5s. a ton. Seeing that these figures compare with about 4 lbs. which Mr. McMahon has given us, it shows that there is a good deal of margin still between the best that can be done under favourable conditions and the best that is done in Mr. Fox.

Mr. Fox. average working. I think the average individual reading the paper would be rather inclined to think from the comparisons Mr. McMahon has made between the Willans engine and the Corliss engine that it would be difficult to get these very low costs with high-speed engines. This assumption would, however, be a mistake, for the following reasons. To get the lowest figures which I have mentioned you are practically compelled to use high steam pressures and fairly high degrees of superheat, superheat between 550 and 600 degrees on the engine. This resolves itself into triple expansion engines, and Corliss engines do not lend themselves so easily to triple expansion working; at all events, you do not often meet them as triple expansion. Lancashire millowners are perhaps "keener" after coal consumption than any one else. They have during the past few years tried to work their engines triple expansion, but on the grounds of first cost perhaps more than for any other reason they have abandoned them, and the tendency at present seems to be compound engines with superheated steam. You come, therefore, to a comparison between high-speed engines running triple expansion and Corliss engines running compound. Then, going on to superheat, you cannot use the same high degrees of superheat on Corliss engines as on high-speed engines, and the final comparison resolves itself into triple expansion high-speed engines with a high degree of superheat *versus* compound engines with a moderate degree of superheat; and comparing them on that basis I do not think there is any comparison at all; the figures are so very much in favour of high-speed engines. There is another point which I think is overlooked very often. When you come to aiming at very low works cost (the lowest I have come across being 0·18 of a 1d., or under one-fifth of a 1d.) the capital charges are a very big percentage of the total costs—about 33 per cent. of the total costs, or 50 per cent. of the works cost. On the one hand refinements are necessary to bring about these low working costs; on the other hand they form a very heavy charge on the total costs; and I think when you come to figure it out you will find that Corliss engines are too expensive for the job. On the smaller sizes up to 600 or 700 k.w., I think they would certainly be out of it on the grounds of price, in comparison with high-speed engines, and above that size they will most probably both be out of it in favour of turbines on the ground of first cost. With regard to the actual figures that Mr. McMahon has given on page 105 for the Willans engines, there are one or two points which I think are misleading. In the first place, in the second table on page 105 the figures actually obtained on test were so much better than those guaranteed, that it brings the comparison between the Corliss engines and the Willans engines a good deal closer together. For instance, 18·5 was promised and about 17¾ was obtained on the Willans engine, a difference of ¾ lb. Taking that very size of engine, and taking the figures which you would obtain in steam consumption under conditions more favourable to high-speed engines, namely, high steam pressures and superheat, we reduce that 18·5 lbs. per B.H.P. down to 11·7 lbs. under ordinary working conditions, that is 11·7 lbs. against about 16·3 promised by the Corliss engine. The same remarks

apply to the lightest loads, the figures obtainable with higher steam pressures and superheat being very much below those given for the Corliss engine. There is one other remark I wish to make, namely, on the subject of repairs and maintenance. Mr. McMahon says that the Corliss engines have cost less to maintain. As a matter of fact the costs are very low, whether it is for the Corliss or for the high-speed engines; but in making a comparison between the two, I think one should couple the items of "labour in the station" and "repairs" together, for the simple reason that high-speed engines cost, apparently, rather more for repairs than Corliss, for the reason that the repairs are carried out over short periods and are all debited to "repairs," whereas in the case of the Corliss engines much of the costs of repairs is debited to running costs, being carried on by the station staff, which is increased for the purpose. If these two items were considered together, it would be found that the advantage lay with high-speed engines. Mr. Fox.

Mr. H. W. MORLEY (*communicated*): I must congratulate Mr. McMahon on the information that he has put before the Institution. The records of running this first English Tube Railway have been exceedingly interesting from the start. The reorganisation of the power plant under his supervision was original in many points; and in many quarters it was predicted that the system of distribution would end in failure. The running costs of the railway have not confirmed that opinion. Mr. Morley.

The power-station possesses a combination of two types of steam engines, the comparison of which has not been previously possible under equal conditions. Most designers of slow-speed engines had watched the development of electricity in its practical inception for electric lighting, but they knew that in the earlier days of small units slow speeds were unsuitable. The development of slow-speed engines for electric work was undoubtedly checked by the enterprise of our high-speed engine builders, who designed, improved and developed the most reliable and economical high-speed engine which is produced in any country, at the same time laying down testing appliances on their own works and by this means forming, as it were, a community of interests between the electricians and themselves, offering many advantages which cannot yet be offered by slow-speed engine makers. To test an engine at makers' works is conducive to the best results at stated steady loads; and to compare any steam engines by their results given on makers' tests, or tests on site, the full conditions of the test require to be known, as well as a full knowledge of the personal element. It is well known that the number of low revolution engines in work in proportion to the number of high revolution is in the proportion of thousands to one; also that the experience of the slower engines goes back for many years, some builders having records of engines at work of the slow-speed type over fifty years old. The wear on these slow-speed engines is exceedingly small, but it has not been usual to make records of the wear, for the reason that the personal element was considered by far the greatest controlling influence in the matter. This personal element is in all engineering work very

Mr. Morley. important, and, in my opinion, prevents comparisons between many similar electricity station costs being used as an argument in favour of any particular type of plant.

At the City and South London Railway, two types of engines, the high and the low speed, have been worked under nearly equal, and with the exception of the load-factor being against the low speed, under exactly equal conditions, viz., same staff, boilers, condensers, etc.; and as far as my information goes, there is no similar place where equally reliable comparisons can be made. From the results which slow-speed engine makers had obtained in factories in the north of England, where many mills are run at a cost of £1 value of coal per H.P. per annum (fifty-six hours per week), and many of these builders having had experience with high-speed engines, these results are no more than was expected and had been argued many times.

(1) *Maintenance Charge.*—Although the slow-speed D.C. engines on which this maintenance has been calculated were the first built in this country for railway work, the cost of repairs, as given in the paper, 0·008d. per unit, is low, and should be a measure of their reliability. In a paper read by Mr. Minshall before the Institute of C.E., he states that Professor Kennedy had informed him that "the cost of repairs at Westminster Electric Light Works did not exceed 1s. per H.P. per annum." From one of the electrical papers I have extracted the particulars, as follows—viz., that the k.w. installed at Westminster were 9,150. The number of units sold is stated as 11,696,000. Taking these figures, it looks as though the repairs per unit output stood at 0·015d., rather lower than a similar type of plant at Stockwell, but still about twice that of the slow-speed engines under consideration.

(2) *Oil.*—In this matter the slow-speed type at Stockwell is not satisfactory; but it must be borne in mind that since the time when these slow-speed engines were made, a reduction in the oil bill, of the type, has been made by enclosing the engines.

(3) *Vibration.*—In London this is often a very troublesome matter, and from comparative tests made with a seismograph, it seems conclusive that the underlying London clay is particularly suitable for transmitting vibration, and that the higher speeds are more liable to synchronise with the vibration of this part of the earth than the lower speeds. It is also noticeable that when exhausting to the atmosphere, the more rapid the emission of the exhaust puffs the more do the windows rattle in the immediate vicinity.

(4) *Economy.*—It is admitted, I think, that to obtain the highest economy automatic expansion must be used, and the design of that automatic expansion gear decides the speed at which the engine shall be run. In this country for large units, 500 k.w. and upwards, 100 r.p.m. is considered the maximum for the Corliss gear or for any form of releasing mechanism. I have confidence that with further experience this present maximum will rise, but at about 135 r.p.m. it is possible to shut the valve as quickly by an eccentric, and at that point similar difficulties arise in the design of automatic expansion gear as are before the designers of high-speed engines. In arranging an engine, viz., whether it is to be high speed, low speed, compound or triple,

the conditions of the load must be taken into consideration. Thus, for low load-factors, as in electric lighting, first cost is one of the main factors; but in greater load-factors economy takes the leading place for consideration. Again, for a continuous but variable load, as in tramway or railway work, the economy must be well maintained throughout the whole variation of the load, and for this duty the slow-speed compound engine with automatic expansion is eminently suitable. It has often been contended that the heavy parts of the slow-speed engine, as 40, 50, and up to 100 tons flywheels, 7 to 50 tons shafts, etc., are against high mechanical efficiency, but experience does not confirm this argument, although I cannot altogether accept some of the high efficiencies which have been put forward both for high- and slow-speed engines. I quite realise, however, the difficulty of obtaining the necessary readings from any instrument not of the balance type for such small percentages of the maximum power. It is known also that steam-engine indicators, even in the hands of the most reliable and careful operator, will vary, as illustrated by tests on indicator springs before and after an engine test, when the scales have been found to vary perceptibly. But it is often overlooked that in a two-crank two-bearing vertical engine, the heavy flywheel, shaft, generator, etc., do not materially affect the friction in a double-acting engine; certainly on the down-stroke of the piston the weight of the parts is added to the weight of the shaft on its bearing; but on the up-stroke the weight of the parts is subtracted from the upward pull of the engine piston; and it will be noticed in most cases the downward weight on the bearing will very nearly balance the upward pull on the crank pin for most loads. Further, for a given piston speed (and the piston speed of slow-speed engines is about the same as that of the high-speed), and the same mean pressure, the cylinder diameters or the sum of the areas will be the same; so that the weight of the moving parts, as piston and rod, have not that great difference in weight that is usually taken for granted; still, the longer stroke engines will have heavier parts, but those parts will not weigh nearly proportionately to the length of stroke. Mr. Morley.

Again, for variable loads the triple expansion engine, owing to its greater internal friction and the difficulty in designing it for carrying overloads, will not in my opinion prove economical either for high or low speed; this type will prove, perhaps, most economical on the test bed at steady load, say, 0·625 to full, but it is not so on a variable load from, say 0·5 load to 50 per cent. overload.

"But," say some engineers, "we do not see the necessity of 50 per cent. overload," and in this matter the question of rating is most important; it will, however, I think be admitted that the fewer the units, the more satisfactory will be any power installation, and if this is true, then that unit which will give the greatest variation of power on an economical basis of economy will be the most suitable. I can perhaps best explain my meaning by an illustration, and for this let us take a set which gives the most economical result at 1000 k.w. output and 150 to 160 lbs. B.P.: then in my experience a compound slow-speed Corliss engine will give on the governor, without very material variation

Mr. Morley. in speed, an output between 0 and 1,500 k.w.; the lbs. of steam not superheated will not vary per k.w. output very materially between 700 and 1,100 k.w.; lower loads will increase the steam per k.w. output slowly and at the higher loads the steam will increase rather more quickly. If now, say, 100° F. superheated steam is used, the steam per 1 H.P. will not vary materially between 450 and 1000 k.w. output, and the engine will turn 1,500 k.w. How are we to rate this engine? A triple engine with its larger ratio of cylinders and even with its slightly increased boiler pressure, could not turn the overload, and an engine with the throttle governor cannot turn above its economical load without using a bye-pass valve or a gear to alter the expansion in the high-pressure cylinder by hand, an obviously undesirable method for ordinary variable loads. Most high-speed engines are of this latter type.

It appears, therefore, to me that in considering the various types of engines available, note should be taken of the possible capabilities of each.

Superheated steam is likely to be a great advantage to high-speed engine builders, for in that engine the initial condensation is the main loss; but for the high-speed engine to give the best result a greater ratio of expansion must be used and the rating consequently lowered. Mr. Fox states that it is impossible to use as high a temperature in Corliss engines as in high-speed engines, which engines of a successful type nearly all use piston valves. Have any high-speed engines been in successful operation with high superheat 600° to 700° F. long enough to say they are satisfactory? Many Corliss engines have been in successful operation for many years with temperatures up to 500° F., and if Corliss valves will not stand a higher temperature, inter-heaters are used to reduce the temperature to 500° F. in the high-pressure cylinder, giving it out to the steam on its way to the next cylinder; and if still higher temperatures are required, the advantages of the low-speed engine can still be maintained by the use of drop or piston valves under more convenient and satisfactory conditions than can possibly be obtained in a high-speed engine of any type, and much more satisfactory conditions than obtain where piston valves and trunks are in direct rigid connection. Although, then, the same reduction of steam consumption by superheating is not possible in slow-speed automatic expansion engines of the best type as in high-speed engines, still experience shows that at least the same percentage of saving can be obtained. But in both types there is yet a possibility of further improvement, and also one awaits with interest the results of experience in actual daily operation of large turbine units on a variable load with a load-factor corresponding to the ordinary railway or tramway load.

I have previously suggested that to compare steam engines by their results given on tests the full conditions should be known; and an engine which will give a good result on a steady load, whether that be full load, ¾ or ½ load, might give quite a different result on a variable load; and this argument is confirmed by taking the tests which were made at Stockwell to ascertain whether the guarantee

had been fulfilled, and of which the figures are given on pages 134, 135; and a comparison of the figures which were obtained in actual service, given on page 137, shows conclusively a further advantage of the slow-speed Corliss engine on variable loads. The comparative figures, then, of 23·8 and 30·2 lbs. per kilowatt output given by the author on page 137 are not closer than was to be anticipated. Mr. Morley.

I should like to put before you the capitalised value of this saving, for this is a measure of the commercial value of the two types. For convenience of calculation I have taken a 1,000 k.w. set, in order to arrive at a load-factor have taken 1,600 k.w. (page 132) as the maximum output, and the electrical papers give the number of units used as 5,400,000, which gives a load-factor of 38·8 per cent. Coal is, I believe, about 15s. per ton for washed nuts—at least this is not a higher price than usually obtains in the London district; and evaporation 8 lbs. of water per lb. of coal. On this basis, then, I calculate that each lb. of water saved per k.w. output is equal to about £140 sterling per annum. In order to capitalise this saving I again referred to the Electrical papers to arrive at the depreciation item, and I found that the average depreciation allowed by the London Companies was just under 2 per cent.; but considering that this applied to other appliances besides engines, and in order to compare more with my own idea of depreciation, I have taken 3½ per cent. To this I have added 4 per cent. interest, as the usual value of debenture stock, and then capitalised the saving on the basis of 7½ per cent. total. Each lb. of steam then saved per k.w. output by one type of plant over another, taking the figures above as the basis, making that plant worth £1,850 sterling, or £1·85 sterling per k.w. output more than the other. Taking Mr. McMahon's figures from page 137, the slow-speed engine shows a saving of 6·4 lbs. per k.w. output, from which I make the saving in coal per annum on 1,000 k.w. set not less than £900. Capitalised on the same basis as before, the extra value of this 1,000 k.w. slow-speed set over the 1,000 k.w. high-speed set would be £12,000, or £12 per k.w. output; and this includes the cost of the engines and foundations. On an average electric light load-factor, say, of 10 per cent., the saving would be reduced to £232, or a capitalised value of £3,100, which would indicate the limitation of the various types.

But as pointed out by the author, in considering power plant it is necessary to consider the whole installation, and by more economical engines saving in boilers, steam pipes, etc., is effected. In the larger sizes, 1,000 k.w. and upwards, the vertical slow speed set occupies very little more space than the high-speed set. They would, however, slightly increase the cost of the buildings.

The life of a slow-speed set is undoubtedly longer than that of a high-speed, but in the consideration of this life the question as to whether a plant becomes obsolete or not requires taking into consideration. The slow-speed engine is a development of many years, as it arrived at its present state by a series of developments, and has not altered materially for many years. Further, when plant is to be discarded the heavier weight of material would demand a higher price, and this

Mr. Morley. therefore leads me to the opinion that the depreciation on slow-speed plant does not require to be reckoned as heavy as the depreciation on high-speed plant.

Mr. Day. Mr. C. DAY (*communicated*): In regard to the Corliss engines, as I was responsible for the design of these engines, I beg first to offer a few remarks in regard to the design :—

Flywheels.—About the time these wheels were designed several American engine builders adopted wheels with steel-plate webs, and the rims built up of steel plates. I saw several such wheels at power stations in the United States, but considered that in consequence of the very large flat sides they lacked lateral rigidity. To overcome this difficulty wheels having the side plates pressed to conical form were designed, and were afterwards submitted to Mr. McMahon, and adopted by him. By adopting the steel-plate construction a wheel having a very large amount of stored energy became possible without its weight being excessive, as a high peripheral speed was practicable. The reason for adopting flywheels having an unusually large amount of stored energy was to simplify the problem of close governing under the severe conditions of an electric railway.

Turning to the question of the stresses to which parts of the wheel are subjected, Mr. McMahon's remark in regard to the large factor of safety may be noted, but I would mention that this large factor of safety not only applies to the stresses which are produced by centrifugal force, but also applies to those stresses which are incurred should severe short circuit take place in connection with the dynamo. The determination of the stresses on the wheel due to centrifugal force was of a somewhat ordinary character, and calls for no special comment, but at the time of designing the City and South London flywheels I had considerable difficulty in ascertaining the measure of the forces likely to be brought into the case should severe short circuit happen. After considerable enquiry I designed the wheel so as to deal safely with a short circuit, the severity of which was such as to stop the wheel dead in one second. Now a short circuit, however severe, would not pull a flywheel up to a dead stop, as, with reduction of speed, the effect of the short circuit would diminish until a balance was produced between the turning moment due to the pressure of steam on the pistons and the resistance to rotation, and when this balance was reached the speed would cease to fall ; but it is reasonable to suppose that during a period of, say, one-fifth of a second, the effect of the short circuit would be such as to absorb a fifth of the energy stored in the wheel (plus the energy due to the steam power). Whilst testing engines I have seen very severe "shorts" occur, and have concluded that the assumption just mentioned is a very fair one and represents a condition which may quite possibly occur, but a more convenient form of expression for use in designing wheels is that first given, viz., that the wheel is to be so designed that it may be brought to rest in one second.

Each of the flywheels is directly bolted to the armature boss, the diameter of the bolt circle being as large as possible. By this arrangement the whole of the stresses brought about by short circuit are

removed from the crank shaft and from the keys driving the armature and the flywheel, and consequently these keys have only to transmit the torque due to the action of the steam on the pistons. Though these flywheels most fully meet the requirements of the case, I am of opinion that they are not likely to be often repeated owing to their high first cost. Mr. Day.

The governors are of the Hartnell type with special bearings for the pins to minimise friction, and were arranged to give a 5 per cent. speed variation between full load and no load, a smaller margin being undesirable for dynamos running in parallel on variable loads.

Steam Consumption.—The particulars given by Mr. McMahon are of great interest and again demonstrate the economical advantages of Corliss engines. I would, however, suggest that the figures would be greatly simplified if given throughout on one basis; for instance, the guarantees for the Corliss engines are given in lbs. per B.H.P. while the test results are given in lbs. per k.w. Transferring the latter to lbs. per B.H.P. the actual steam consumption appears to be 14·3 lbs. per B.H.P. against 16·3 guaranteed, and at the overload the actual lbs. of steam used were 14·6 lbs. per B.H.P. against 17·5 guaranteed.

In comparing the Willans results some allowance needs to be made for the better vacuum at the time the Corliss sets were tested, but I note that the dryness of the steam is not given for the Willans tests; it is probable that they would have an advantage here. In the Corliss tests 4·5 per cent. of moisture was present in the steam, and a deduction of 4·5 per cent. was made from the amount of steam used, to allow for this moisture; this deduction, however, is not sufficient, as the presence of so much moisture would be very prejudicial to economy. Also, I would add that so far as my experience goes, the type of calorimeter used would not indicate the full amount of moisture.

On page 138, Mr. McMahon clearly states the true aspect of the questions to be considered when deciding between different types of engines, and as I was responsible for the steam consumption guarantees given to Mr. MacMahon in respect of the Ferranti engine I would say here that the figures were based on actual results obtained, and an allowance was added as a margin for contingencies. There is, in my opinion, therefore, little fear but that the actual results will in this case again be better than the guaranteed results, as was the case with the Corliss engines, in connection with which I was equally responsible for the guaranteed steam consumptions.

Mr. P. V. McMahon, in reply: I will reply to the various speakers in the order in which they took part in the discussion, because my notes are so arranged. With regard to Professor Carus-Wilson's question as to the necessity of using the third rail earthed in the three-wire system, that has been dealt with fairly fully by Mr. Sayers; and I see no reason why all conductors should not be insulated, with the return earthed at the generating station, in which case you have practically the same conditions as now obtain with the three-wire system and an earthed return. A good deal of stress was laid upon the advantage of an insulated return byboth Professor Carus-Wilson Mr. McMahon.

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and Mr. Hobart, on the ground that if you have an earth on a motor you can wait till you have another one before you get a breakdown. I think that is like living in a "fool's paradise," because if you get a fault in the motor the sooner you break it down the better. If you have two motors, either in the locomotive or in a motor-car train, and imagine a fault on the positive side, which you do not know anything about, supposing a fault appears on the negative side of the other motor, when the second fault develops, your locomotive is absolutely broken down altogether, whereas with the earthed return, as soon as you get the first fault you throw one motor out of service, and come home on the other without delaying the traffic. You must remember that with tunnel lines the public are easily alarmed, and the main thing to be aimed at is to avoid delays. Professor Wilson also stated that the electric locomotive was nearly extinct. With that statement I do not agree, and in the light of recent events I think the electric locomotive for tunnel work will hold its own. We thought we had extinguished it some six or seven years ago, and with that object in view we built a motor-car train, which had nearly 25 per cent. greater seating capacity for the same weight as with locomotives, but we found in tunnel work it was not nearly so successful as the locomotive for the following reasons: any slight repairs to the motors or switch-gear in the case of a motor-train means shunting the whole train of four coaches into a siding about 130 feet long, while the same work on a separate locomotive could be executed in a siding about 15 feet long, so that the siding accommodation required for motor-trains is a very serious item. Again, while under repair the whole motor-train is thrown out of service, and with separate locomotives the train continues in service, and a smaller number of carriages are required. The advocates of the multiple unit system say that the train can be broken up into independent units, but this involves an enormous amount of shunting, unless fan-tail sidings are available, which is almost impossible in a tube railway system. The Board of Trade also object to having motors under the intermediate coaches, so that with motor-car trains you are practically bound down to a motor-car at each end of the train. In the case of the Central London Railway they are able to run their trains to the surface by their own motive power, and the question of shunting does not in their case disorganise traffic to the same extent as on the City and South London Railway, where all the rolling stock is hauled to the surface by a winding engine. The method adopted at the Central London, while having many advantages, involves a great increase in light engine mileage, which is very unprofitable. Upon surface railways the case is very different, and here no doubt the motor-car train will increase in popularity. Mr. Hobart rather objects to the number of boosters and transformers and that sort of thing that we have on our system. I think he was rather frightened at the diagram. My endeavour to simplify the diagram has given it a complicated appearance. Instead of there being four armatures to each reducer, there are only two double-wound armatures. If I had to do the whole thing over again I would certainly go in for the same system, but there are one or two things that I should avoid.

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For instance, I should try to have the switch-board simplified. We would not use perhaps such small sets as 125 kilowatts. If one had a free hand, the old Mather and Platt generators, for which we had great respect, would not be used again, but at the same time they were there, and represented a certain amount of capital, which either had to be written off or sold at a loss. They came in all right coupled together as motor generators; and the only disadvantage we feel is that we do not get as good a voltage regulation with them as we do when we use the steam boosters. Mr. Hobart was also not at all in favour of using batteries. That may be all very well from the point of view of a man who designs a station and clears out of it as soon as it is running, but it is altogether different when a man has to live with it. It has been our salvation many a time, when we have been able to fall back on the batteries even for only a quarter of an hour, when there is something wrong in the generating station. You have the advantage that if you have a heavy short circuit on the third rail you are able to maintain your lifts and lighting absolutely independent of the generating station; and if there is any trouble, which we have experienced, of trains fouling the third rail and making it necessary to cut the current off, in which case the passengers have had to walk on the foot-board to the next station, the lifts and the lighting have been kept going, and if we had not had our batteries we would not have been able to do that. Mr. Hobart also thought that if we went in for a continuous system of distribution we might go in for 4,000 volts. I quite agree with him that 4,000 volts would be preferable from the distribution point of view; but three or four years ago, and perhaps even now, you might have had some difficulty in getting the Board of Trade to agree to such a high voltage as 1,000 volts on the motors in the tunnels; but suppose you did use 1,000 volts, would the increased efficiency compensate for the additional safeguards necessary when using such a voltage. Mr. Bjornstad referred to the question of the ropes on the lifts. I am afraid that is hardly a subject in which the members of the Institution of Electrical Engineers are as deeply interested as if they were face to face with it every day, but still the fact remains that the rope question has a very important bearing on the success of electric lifts. There is no doubt that the longer life of a rope on a hydraulic lift when compared with the electric is in our case due to the ∿ drive and to the confined space in which we have been obliged to place the machinery. That is fairly well proved by the fact that on the Angel Extension, where the machines have been placed over the shaft and a number of the guide pulleys done away with, the life of the ropes is about twice what it is on the stations where the machinery is placed underneath. Then again, with regard to the form of drive used, it is very neat so far as it gives a grip on the rope, but there is no ropemaker who does not object to bending the rope first in one direction and then in the other; they all agree that it shortens the life of a rope tremendously. Perhaps, while dealing with the question of ropes, I may refer to Mr. Brown's remarks, as he dealt with lifts. He took exception to my saying that the first cost of the electric lift is equivalent to the first cost of the hydraulic. I quite

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agree with him when the lift only is considered, but I was assuming that if you have to install and work electric lifts at a distance from the station, compared with a hydraulic lift the electric lift comes much cheaper. With regard to the question of economy, I do not know whether I drew attention to it in the paper, but the actual coal consumption for ten hydraulic lifts is equal to the coal used for twenty-five electric lifts. We have five stations fitted with hydraulic lifts, ten hydraulic lifts in all, constantly working, the remainder being electric, and the coal consumption for each system is about the same, so that if we can get over the difficulty of starting, stopping, and regulation, as it had been done on the hydraulic, there is no doubt about it that the electric lift will prove better than the hydraulic. Mr. Brown hoped that some one would bring forward a happy combination of an electric and hydraulic lift. I do not know whether it was Mr. Brown's modesty which prevented him mentioning a very good lift of his own; but he has brought out a balanced electro-hydraulic lift which, to my mind, gives you all those conditions. The only objection I see at the present moment is that to avoid the pulsation from a three-throw pump you are obliged to use an accumulator, and that more or less does away with the advantage you get from the direct combination, but I dare say he will overcome that. Mr. Stevens referred to the question of circuit breakers. I agree that there are some objections in having a resistance in parallel, but there is this to be said for that arrangement: it saves the switch contacts, and the man in charge of the generating station is able to see at once practically what is going on. He can see from the ammeter whether the short is permanent or temporary, and the resistance across the circuit-breaker is such that he can limit the output of the generator to the normal load of the machine. For instance, if the normal load of the machine is 500 amperes, the resistance is so arranged that on short dead circuit he can only get 500, and if that current remains on for any length of time there is another switch in the circuit by which he can cut the feeder off. I quite admit that it is a disadvantage in having the resistance across in the case of a broken-down cable, because you are pouring current into the fault. But in our case each section has a switch fuse. We have had cases where we have burnt up several inches of the cable before we were aware of what was going on, and the current cut off; if the short is a bad one the section fuses blow and clear the fault. Mr. Stevens also referred to the suggested regulations for the Paris railway. I do not know whether he mentioned when these regulations were actually put in force, but I may say that we have had switch fuses in each section since the line opened, and we have lately put telephonic communication between the locomotive and the stations. We always had local telephone communication from station to station, and we have now put in bare wires on the side of the tunnel, and each locomotive has a telephone, so that if the driver is in trouble, in order to save time he simply rings up the nearest signal-box and communicates with somebody in the station. Again, if a train is delayed for more than three or four minutes in the section, the signalman in the station switches on the tunnel lights, which are placed every fifty feet and supplied from an

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independent cable, so that if the people in the train have to get out they can walk to the next station through the lighted tunnel. Mr. Booth referred to the coal consumption as being only what was arrived at some thirty years ago, and referred to an arrangement of I do not know how many cylinders. I take it that the good results then obtained was due to a constant load and not in any way to the arrangement adopted. With regard to the dryness, the tests taken were made by Mr. Morley, and I am sorry he has not referred to them. In our case it would be impossible to take a test of the dryness of the steam, because we do not super-heat, and we could hardly adopt the method of taking the dryness with a thermometer. I think, too, in taking the cost per unit, Mr. Booth compared our costs with the costs that were obtained probably near a colliery. Although the coal that we burn costs about five shillings a ton at the pit mouth, it costs on an average thirteen shillings and ninepence a ton before we get it into our yard, and sometimes more. In fact, the cartage of our coal from the riverside costs us something like one shilling and threepence to one shilling and sixpence a ton before we get it into the yard. Mr. Jones referred to the water meter, and wondered why we are not satisfied with the suction meter. The idea of having one between the pump and the boiler was that we actually get water pumped into the boiler, and there is no chance of leakage. I made inquiries about the suction-water meters, and found opinion divided, so I thought the best thing was to do without them altogether. We put meters on the condenser, and fitted measuring tanks by which we could take tests every now and then, and calibrate the wier pumps which have counter attached, giving a fairly accurate idea of the water pumped into the boilers. As to the question of motor-driven pumps for the boilers and the condensers, we went into that fairly closely when the new plant was put in. There was one objection to having a motor-driven pump, namely, that unless you have a battery—and we had not a battery in the engine-house when we first started—you cannot start your pump without having a generator going, and therefore we had our pumps steam driven. There is another rather important point as far as the condensers are concerned, I gave this particularly because it is an easy comparison. Our air-pumps would have cost nearly double as much if they were motor driven, and that is also a consideration.

Mr. Patchell.

Mr. PATCHELL: May I ask whether it means capital or maintenance?

Mr. McMahon.

Mr. McMAHON: Capital. Although Mr. Jones advocated electrically driven pumps he likes to keep his steam pump in reserve. And I would suggest that two steam pumps cost about the same as one electrically driven pump; the exhaust steam can be used for feed-heating purposes and with this arrangement the economy in both systems is equal. Our bonds are of the "Neptune" type. The whole is reimered out, and a bond put in, and a round peg driven in tight. We have not had any trouble that we have been able to detect from the point of view of contact resistance, but we have had trouble in the first instance through the wires of the bonds being too stiff; we had a tremendous number of them broken off quite short. Now we have made the bonds longer and

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of much smaller wire, keeping, of course, the same cross-section, and this seems to have got over the difficulty of broken bonds. I think with regard to Mr. Jones' figures of cost per unit, if I remember rightly he burns Welsh coal, which is, perhaps, better than we have been burning; we burn North Country coal and all sorts of small coal. He also referred to the units per ton-mile at the switch-board and on the locomotive. It is rather hard to get units per ton on the switch-board because we have no meters in the third-rail feeders, and I am not able to give it to you very accurately. You can hardly arrive at it by taking lifts and lighting, as there are so many signal and other lights coupled to the working conductor. I think the reason that Mr. Jones gets a better result in units per ton mile is because the sections are so much longer than ours. We found out from locomotive tests on the line that of the total energy used in taking a locomotive through a section one half of it was used in accelerating the train. Our sections are about half a mile, so that if you double the length of the section you will proportionately reduce the energy used per section, because you only have one start against two. Our load is very steady: that is due to the fact that the lifts and lights are practically all taken from the same 'bus-bars. Mr. Jones also referred to the failure of locomotives. I am able to give you a better figure for the last half year than the figure given in the paper, which was 1·6 per cent. in six months. That has been reduced in the last half year to ·048 per cent., that is for locomotive failures pure and simple. With regard to Mr. Clark's remarks, the Willans engines were tested at the makers' works, and the Corliss in our own station when erected. The boiler pressure is practically always 150 lbs. to 160 lbs. In the particular test to which he referred the pressure may be taken as 150 lbs. The load on the station on the date to which he refers is given in Figure 16. The Corliss engines ran for 17·5 out of the 18 hours, and during the heavy load the Willans engines ran for about 8 hours in addition to the Corliss engines. Mr. Clark also made some reference to the capital charges for electric lifts; that was dealt with in my reply to Mr. Brown's and Mr. Bjornstad's remarks. He also suggested double generators. That was very fully considered too. At first sight it looks a much more convenient method than having single machines. There are times when you want to put a small engine on in the middle of the day or late at night, when you are not running so many trains, and then if you have a double generator, or two generators on the one engine, you are simply running the engine round and only using one generator. It also complicates the switch-gear, and at the present moment with the three-wire system it is quite complicated enough. The question was raised as to the difficulty with our pipes. All the pipes we have in our tunnels are insulated as they leave the tunnel; the gas and water pipes have an insulated flange between them when they leave the tunnel, as required by the Board of Trade. The question was raised as to the Highfield boosters being incapable of taking the variation of current. We can regulate them to do more than they were doing there; we rather let the reducers take up a lot of balancing purposely, because we did not care to discharge the battery too heavily. We try and keep the cells

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fairly charged, so that we are able to use the battery in a breakdown; if required we could make the Highfield booster take up a great deal more of the peaks than we do at present by altering the variable diverter. I cannot see how a short circuit on one side of the system could possibly raise the pressure on the other side to 1,000 volts, as you immediately short-circuit the machine. I quite agree with Mr. Sayers that if the return rail was insulated throughout it would be better earthed at the generating station so as to avoid shocks in the tunnel. We have a good deal more leakage on the negative side than the positive, we have more trouble with the insulators on that side than the other. Mr. Patchell rather condemns the double range of steam pipes. Perhaps he is right, but still one does not care to hang on one pipe only; I would rather be safe and sure than aim at very high economy with an element of risk. As to the jockey pullies in the old station, they have come in for a good deal of criticism, and a good many engineers who have seen them have always maintained that they waste power. There is one little way we had of showing there was no upward thrust. After running some time the brasses get worn on the bottom side, showing that all the wear was downward, and the blade of a knife could be inserted between the top of the brass and the jockey pulley shaft, showing clearly there was no upward thrust; the jockey pulley simply transferred the sag of the belt to the driven pulley and gave a better grip. The fields of the balancers are not crossed, but they have a compound coil. Mr. Fox referred to some very good results obtained in works where probably the load-factor approaches 100 per cent. I think he mentioned the coal as being about five shillings a ton at the pit mouth, which compares with ours, but about 8s. 9d. has to be added for carriage. As to the question of the relative first cost of the Corliss or high-speed engines, there is no doubt that the Corliss is out of it for low power. We found that out in putting our plant down, but I think for powers above, say 500 kilowatts, a fairly high-speed engine with some sort of Corliss gear is an advantage, and our results have certainly led one to think so. Some people may think that I am slating the Willans engines, but I am not. I do not think that I should care to be without them, because they are very handy for starting and running up in a hurry, but for higher powers they certainly take more steam per kilowatt. After the Willans engine Mr. Fox would rather favour the steam turbine; I am inclined that way, but we would like to see a little more of the steam turbine before going in for it largely. I do not quite agree with him that the Corliss engine costs more for repairs than the high-speed engine. We have had very little repairs to either. In one case we had to renew some pistons because the Insurance Company did not consider them safe, and in another case we had a nut come off the Willans valve rod, which broke up the trunk. They were the two biggest items given here, otherwise I think there is very little difference. All repairs costs whether at short periods for the Willans or Corliss are given in my figures, and the station staff is not increased by reason of the Corliss engines. In fact, I think it would be difficult to run the station with a smaller staff even if it contained only Willans engines.

The President.

The PRESIDENT: I take it, by your applause, that Mr. McMahon is given your heartiest thanks for the paper he has read.

Dr. Thompson has been kind enough to translate the paper by Dr. Hans Behn-Eschenburg, which has been distributed among you, and to save time he is now prepared to lay the subject before you in abstract.

The following paper was then read in abstract by Dr. S. P. Thompson :—

ON THE MAGNETIC DISPERSION IN INDUCTION MOTORS, AND ITS INFLUENCE ON THE DESIGN OF THESE MACHINES.*

By Dr. HANS-ESCHENBURG, of the Oerlikon Machine Works.

Professor S. P. THOMPSON: I think we are greatly indebted to Dr. Behn-Eschenburg and the Directors of the Oerlikon Company for the permission they have accorded him to publish these important experimental data, the like of which we have not had before. I think the least we can do is to return our thanks to Dr. Hans Behn-Eschenburg that he had so freely put his experience at the disposal of the Electrical Engineering industry.

The PRESIDENT: I would like to endorse what Dr. Thompson has said with regard to the debt that is owing to Dr. Hans Behn-Eschenburg and his directors, and it gives me much pleasure to propose that our best thanks be tendered to these gentlemen for the important contribution which has been made to our proceedings.

We are also very much indebted to our friend Dr. Thompson, for the exceedingly clear way in which he has placed the paper before us, and I ask you to accord him your best thanks also.

The votes were carried by acclamation.

The PRESIDENT announced that the scrutineers reported the following candidates to have been duly elected :—

Members.

Reginald H. H. Boys, Captain R. E., D.S.O.
Thomas Fletcher.
Thomas W. Fowler, M.Inst.C.E.
Emil Kolben.

Associate Members.

John Aitchison.
Frederick C. D. Atkin.
William Baker.
Horatio Bell.
William F. Bolton.
Alfred H. Burbridge.
D. G. Cunningham-Phillips.
Cyril C. T. Eastgate.
William Frisby.
Arthur Gavey.
Joseph Jeffries.
Waldemar Jensen.
John J. H. Johnston.
John F. Jones.
Henry H. Kenshole.
Carl Kinzbrunner.

* The Text of the paper is printed on page 239 *et seq.*, with the Report of the Discussion.

Associate Members (continued).

Percy V. Lockey.
William McClelland.
Hugh G. McHaffie.
Arthur B. Mallinson.
James F. Moore.
Albert Moorhouse.
William George Murrin.
Horace C. M. Patten.
Alfred McGregor Peddie.
Frank C. Perkins.
George H. Swetenham.

Associates.

James B. Allen.
John R. Andrews.
Herbert H. Bates.
David G. Brooks.
Wilfred L. Browne.
Colin M. Campbell.
William B. Carrick.
Fred Coutts.
Harry Curwen-Hazel.
Ernest C. R. Deefholts.
Charles F. Gray.
Frank A. Hill.
James Jackman.
Louis H. King.
James McFall.
Sydney C. Matthews.
John Murray.
Frederick W. Peers.
Harry S. Polybank.
John W. Record.
James Scott.
Percy R. Stevenson.
William Tapley.
Theodore E. Thomas.
Harvey Whittle.
William T. Woodroofe.

Students.

Arnold F. K. Allbrook.
Henry G. Andrews.
Henry F. E. Barker.
J. F. Bayley.
James T. Becklake.
Emil A. Biedermann.
William H. Carey.
Edwin V. Caton.
William H. C. Coates.
Robert W. Colley.
F. Collins.
John C. Connan.
Howard Cook.
Fred Cross.
George S. Cross.
Arthur Cunnington.
Ronald S. Dolleymore.
John R. Duigan.
David A. Dwyer.
E. H. Maurice Eldridge.
Wilfrid A. Erlebach.
Charles R. Fairey.
Samuel K. Ferrier.
John W. Fidoe.
Cecil L. Fortescue.
Harold V. Gibbs.
Frank L. Greenhouse.
Hugh W. Gregory.
Reginald V. Gregory.
Victor J. Harraway.
Rowland A. Harris.
Roseman Harte.
Charles A. M. Henderson.
Charles F. Hewitt.
John C. Holland.
Louis J. Houdret.
Robert A. Humphrys.
Sydney Imray.
John Jackson.
William A. Jones.
Archibald Kennard.
Vivian B. H. Knight.
Harry C. Lott.
Alexander W. F. McEwan.
Rowland Maloney.
Arthur W. Mansfield.
Humphrey F. Mason.
Francis E. Meade.

Students (continued).

Jeffrey S. Messent.
John E. Minchin.
Licis Da Rocha Miranda.
Thomas Mitchell.
Alexander Morrison.
Leonard Nicholson.
Thomas F. Nicholson.
Walter L. Nickels.
Abdel M. Omar.
Alexander J. Paterson.
Edward R. Peal.
Cecil M. Perrin.
Francis N. Pickett.
Edward Player.
E. H. Pollett.
Graham L. Porter.
Bruce G. Rae.
William O. Randall.
Clifford G. Rattray.
Frank W. C. Roberts.
Harry H. Roberts.
Isaac V. Robinson.
Philip P. Sandford.
Eric D. S. Shelmerdine.
Charles O. Silvers.
John P. Smith.
J. B. Sparks.
Arthur Sterling, Jnr.
William F. S. S. Symes.
Humphrey J. Trust.
Percy D. Webb.
Richard H. White.
Arthur G. Whitfield.
William J. Williams.
Maurice Windsor.

The Four Hundred and First Ordinary General Meeting of the Institution was held at the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, January 28, 1904—Mr. ROBERT KAYE GRAY, President, in the chair.

The PRESIDENT: Gentlemen, you will be sorry to notice that Mr. McMillan is not sitting at the table to-night. I think you would like to know that although he has been ill for the last ten days or so, he is going on well, and that we hope to have him soon in his accustomed place. His illness is due to overwork and the inclement weather.

The minutes of the Ordinary General Meeting held on January 14, 1904, were, by permission of the meeting, taken as read and signed by the President.

The names of new candidates for election into the Institution were taken as read, and it was ordered that they should be suspended in the Library.

The following transfers were published as having been approved by the Council:—

From the class of Associate Members to that of Members—

Alfred Edward Jackson.

From the class of Associates to that of Associate Members—

Alfred James Ryan. | C. A. M. Smith.

Messrs. H. M. Sayers and R. W. Hughman were appointed scrutineers of the ballot for the election of new members.

Donations were announced as having been received since the last meeting—to the *Building Fund* from Messrs. H. G. Andrews, A. W. Beuttell, G. Binswanger-Byng, M. Binswanger-Byng, J. B. Braithwaite, H. W. W. Dix, A. H. Finlay, and H. W. Kolle; and to the *Benevolent Fund* from Messrs. H. B. Mitchell, W. M. Mordey, H. Owen, J. H. Rosenthal, K. W. Sutherland, F. Wardrobe, A. P. Whitehead, and C. E. Wigg, to all of whom the thanks of the meeting were duly accorded.

The following paper was then discussed:—

THE EDISON ACCUMULATOR FOR AUTOMOBILES.

By W. HIBBERT, Associate Member.*

The problem of making an accumulator with an alkaline electrolyte has been before the world for many years, and has been attacked by a fairly numerous body of workers. It is known that Mr. Edison is one

* Read at Meeting of November 26th, 1903.

of this number, and various public statements have appeared as to the results of his labour. Most of these can be neglected as void of authority, but the account published by Dr. Kennelly before the American Institute of Electrical Engineers was evidently based on carefully executed work. From this paper we learned the general nature of the cell, together with certain useful numerical data. 14 watt-hours were obtained from one pound weight of the cell, the average E.M.F. being about 1·25 volts.

It is not necessary to repeat here the other data from Dr. Kennelly's paper, as they will be brought up to date by the facts to be quoted from my own tests. It is sufficient to say that very little was done during the next year. The matter seemed to fall into the background, and public opinion settled down to a vague belief that the cell had not yet reached the commercial stage. Indeed, I have heard doubts expressed as to the very existence of the cell. To some extent, I shared this scepticism, not because I doubted the existence of the accumulator, but because of its constitution. I doubted (and expressed my doubts in print) whether the plates would be altogether free from local action, and whether a very small amount of this weakness would not be sufficient to destroy the plate. These fears were based on the data afforded by Dr. Kennelly's paper, more especially the thinness of the plates, and also the probable results of mixing graphite with the active material.

Such anticipations were, I suppose, quite legitimate as anticipations, but they have not been justified by the results of actual trial. It is one of the striking features of the cell, that it recommends itself by work more than can be done by any verbal account.

In the early part of this year, I obtained three of Mr. Edison's cells of small size, and in early June was provided with a Standard Automobile cell. Finally, during part of my summer vacation I was able to run about 500 miles on an automobile driven by 38 Edison cells. The general results of the work done on all these will be described in this paper. I shall confine myself to a somewhat simple statement of the facts verified by myself, feeling sure that these will be most acceptable to the members of the Institute. But it may be worth while mentioning that well-known men at Milan, Paris, etc., have obtained laboratory results which agree in all the main particulars with my own. They have not as yet had the opportunity of testing on the road. A brief description of the cell will be advantageous.

Standard Automobile Cell.—This contains 14 positive and 14 negative plates. Each plate is made of sheet-steel, nickel plated, punched with 24 holes of rectangular shape. In each of these holes is inserted a flat pouch or pocket containing the compressed active material. The walls of these pockets are perforated by exceedingly fine slots or holes, through which the liquid can penetrate. Thus the current can easily pass to and from the active material contained in the pockets.

Active materials.—Both positive and negative plates are alike, except in respect of the active material. The pockets on the positive plate contain nickel peroxide; those on the negative plate contain finely divided iron. Each of these active materials is, I understand, mixed with flake graphite.

Electrolyte.—The liquid is a 20 per cent. solution of potash.

Arrangement.—The plates are fixed very near each other. Yet there does not seem to be any danger of short-circuits. The plates are thin, it is true, but being made of steel, they are thick enough to give rigidity. As a further precaution, vulcanised rubber separators are put between the plates, making the whole a compact mass, whose stability is calculated to resist all the ordinary mechanical shocks it is likely to undergo.

External arrangements.—The cell is sealed in its steel case, the top being fixed on by a special solder not acted on by the potash. Two stout connecting-pins (from the positive and negative plates respectively) come through liquid-tight bushes of vulcanised rubber. These pins are made slightly conical, as are also the connectors which fit on them, and the mechanical finish and easy grip of this terminal add to the value of the battery. The connector is further secured by a screw-nut and fastening-pin. The connector has a much higher conductivity than those of the ordinary type of accumulators.

On the top of the case there are also :—

(*a*) A spring stopper with rubber flange, covering the hole by which the electrolyte is introduced, or distilled water added from time to time.

(*b*) A vent hole guarded by a gravity valve. This provides for the escape of the gas evolved during charge. The hole and valve are covered by a gauze nipple, which prevents escape of spray while allowing gas to pass. It also prevents any flame finding access to the interior of the cell through the stream of evolved gas.

The complete cell stands 13 inches high (overall) and measures $5{\cdot}1 \times 3{\cdot}5$ inches horizontally. It weighs 17·8 pounds. A large part of the external steel case is corrugated to increase its rigidity.

An immediate consequence of examining these features of the cell, is to impress the observer with their admirable fitness—perfection is hardly too strong a word. That which is so lacking in ordinary accumulators—mechanical strength or design—is here in obvious and large measure. The general mechanical structure of the cell is well calculated to remove or to diminish any antecedent adverse opinion.

Electrical data.—The E.M.F. is 1·33, though as there is a very persistent gaseous polarisation effect, the figure cannot be regarded as quite rigid. For a long time after charging it is much higher. The internal resistance is 0·0013 ohm. The output at 60 amperes is 210 watt-hours, = 11·8 watt-hours per pound.

The diagram Fig. 1, on page 206, shows the arrangements used for charging and discharging.

E is the cell under test. *t t t*, pieces of trolley wire used for connections. $M_1M_2M_3$, mercury cups standing in a large tank full of oil.

R, a standard resistance = 0·01009 ohm, verified by the Board of Trade.

V and A, voltmeter and ammeter, both re-calibrated for these experiments.

Large lead accumulators were used for charging E. For the purpose of charging, constantan resistances of varying value and

diameter were used to bridge M_1M_2. For discharging it was necessary to bridge M_2M_3 as well. The control of either strong or weak currents was quite easy and rapid by putting constantan wires in parallel across the mercury cups. In very few of the experiments did the current vary as much as 1 per cent. The average variation was probably about 0·3 or 0·4 per cent.

The curves in Fig. 2 tell their own story.

A striking feature of the curves is the relatively high value of the capacity at the higher discharge rates. The difference in ampere-hours at 30 and 60 amperes is almost negligible. Even at 120 amperes the capacity is 93 per cent. of the maximum, and at 200 amperes is still as high as 82 per cent.

These results at once indicate a valuable feature of the cell for many

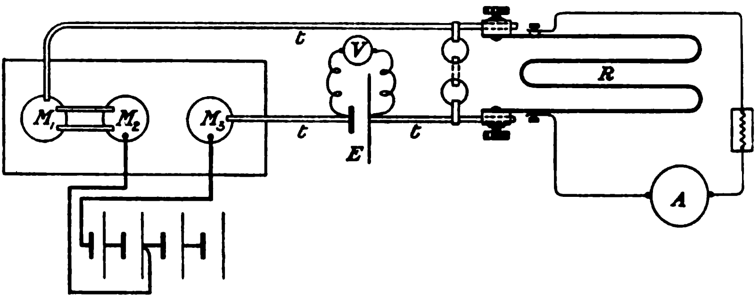

FIG 1.

of the emergencies of engineering. That the quantity obtainable at the high rates should be such a large proportion of that possible at low rates is both surprising and agreeable.

Output.—In relation to the weight of the cell the work done is higher than usual. Taking the output at 210 watt-hours,* and the weight at 17·8 lbs., the specific output amounts to 11·8 watt-hours per pound of cell. This must be regarded as a high figure. It is true that nearly equal figures have been obtained with other cells, but confessedly at considerable risk. The weight of lead cells is reduced by making the supports very thin, but this shortens life. Output can be increased by using stronger acid, but this leads to rapid loss of charge if the cell stands idle. These serious risks do not accompany the method of getting high specific output in the case of the Edison cell. It is, as we shall see, able to retain a large proportion of its charge for a long time, and its relation to "life," although not yet fully verified by my work, is one of very considerable security as far as can be judged by the results already obtained. In relation to volume, the specific output is 1565 watt-hours per cubic foot.

Influence of Temperature on Output.—In the case of lead cells, this is very marked. With the Edison cell, no definite series of experiments has been made, but accidental circumstances afford evidence of some

* This is at 60 amperes: at 30 amperes the output is somewhat higher.

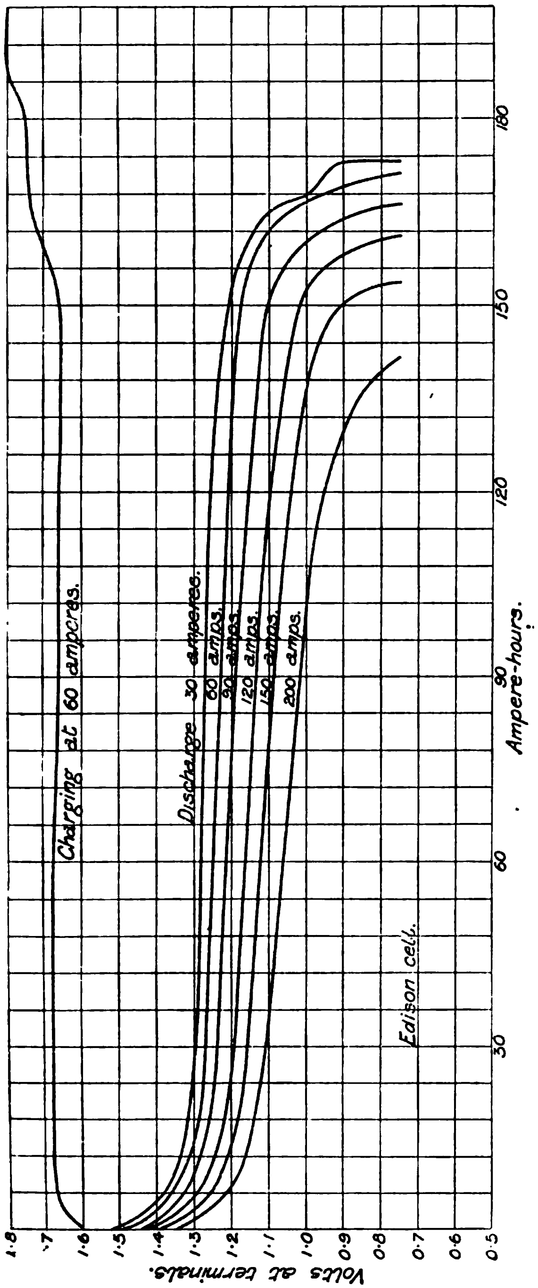
Charging at 60 amperes.
Discharge 30 amperes.
60 amps.
90 amps.
120 amps.
150 amps.
200 amps.
Edison cell.
Ampere-hours.
30
60
90
120
150
180
Volts at terminals.
1·8
·7
1·6
1·5
1·4
1·3
1·2
1·1
1·0
0·9
0·8
0·7
0·6
0·5

FIG. 2.

interest. Some discharges were taken on two of the few very hot days of last summer. The high temperature of the air, added to the heating effect of the currents, caused the temperature of the cell to rise very high. With a current of 150 amperes, it reached 54° C. The output rose to 163 ampere-hours, some 9 ampere-hours more than were obtained at a temperature of 33 degrees. This is an increase of 5·5 per cent. in capacity for a rise of 21 degrees, or an increase of 0·26 per cent. per 1 degree rise.

Other experiments, not specially designed to test the point, indicated a detectable but small increase. The effect is, however, very much less than with the lead cell. With them, it may be 2 or 3 per cent. per degree centigrade. With the Edison cell, a few degrees difference in temperature would produce hardly any change in the quantity output.

This difference in the effect of temperature doubtless arises from the difference in the nature of the actions going on in the respective electrolytes. The continued working of the lead cell demands a continued supply of the acid at the internal working faces of the porous materials on the plates, and a rise of temperature helps to provide this by increasing the rate of diffusion of acid from the outside. In the Edison cell there appears to be practically no need for diffusion or circulation of the liquid. It is not an active material in the ordinary sense; it acts only as a conductor. Hence a higher temperature cannot change the action except by diminishing the internal resistance of the cell. Even here the action must be differential. For the liquid will diminish in resistance as the temperature goes up, while that of the plates themselves will increase. The first of these, however, being the greater, will determine the resultant change, with a consequent increase in chemical action before the pressure falls to a limiting value. For example, in the experiment described, which led to a final temperature of 54° C., the resistance of the electrolyte would be about 30 or 40 per cent. less than in the corresponding experiment at 33 degrees.

It is also of interest to note that these experiments at higher temperatures were the earliest. The other experiments described in this paper were all done subsequently, and therefore show that no injury had resulted from the heating due to higher external temperature and also to the excessive currents passing through the cell.

INTERNAL RESISTANCE.

It is not easy to determine this except at times when the pressure curve is tolerably flat. Attempts were made, however, to get an approximation by opening the circuit for a moment or two and noting the rise in volts at the terminals. The value—

$$\frac{E - V}{C}$$

comes out as a tolerably constant figure from the various curves in Fig. 2. It rises from 0·0013 ohm with the lower currents, to 0·0016 with the higher. The value does not vary appreciably over the greater part of the discharge. But towards the end, where the pressure begins

to fall quickly, the resistance rises at a fairly rapid rate. At the end it may approach 0·004 or 0·005 ohm.

SHORT CIRCUIT.

With the object of testing the power of recovery, one of the small cells was partially discharged, and then short-circuited for forty-eight hours. After a subsequent long charge it gave the discharge curve B, Fig. 3. Compared with the normal discharge curve A, B indicates a deficiency. It is evident that the cell has not yet recovered. On charging again, however, and taking a second discharge (curve C), the deficit hardly appears; the cell has practically recovered from the harsh treatment to which it had been subjected.

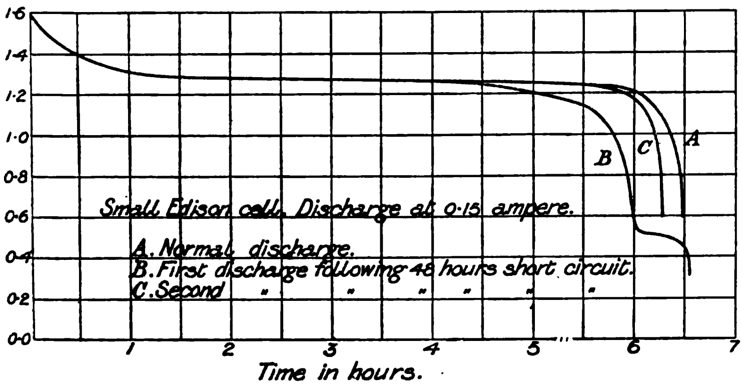

FIG. 3.

HIGH RATE OF CHARGING.

The foregoing experiments prove conclusively that the Edison cell can maintain a high rate of discharge. The interest of this question hangs on its maximum charging rate, and this I have not been able to reach. The following curves, Fig. 4, show the course of an experiment made to test this point. The cell was first carefully discharged at 30 amperes down to 0·75 volt. It was then charged for one hour, 177 ampere-hours being put in. The current was not quite steady, varying from 180 to 176 amperes over most of the time. Near the close of the hour it fell to 166 amperes. The subsequent discharge shows that 124 ampere-hours were delivered, which equals 70 per cent. of the charge.

Further experiments on this point appear in the later section dealing with the motor-car work, proving that the cell can be charged at over 200 amperes.

FLEXIBILITY OF THE CELL.

The new cell will probably be called upon to stand very rapid and large fluctuations in the value of the current. The following curve,

Fig. 5, shows that it behaves like an elastic structure, its pressure rising and falling with varying demand, but responding at such a rapid rate that the lines of changing pressure appear vertical on the diagram. The change to and from 230 amperes will appear more trying if the weight of the cell be kept in view.

Continued Discharge at Lower Voltage.

In most of the experiments so far described, the discharge was stopped when the terminal voltage fell to 0·75. At this point, as all the curves show, the pressure is falling rapidly, and would lead to the assumption that it must speedily reach zero. But this is not the case. At a still lower pressure the rate of fall suddenly alters, and the curve becomes flat again. Presumably this is due to a secondary chemical

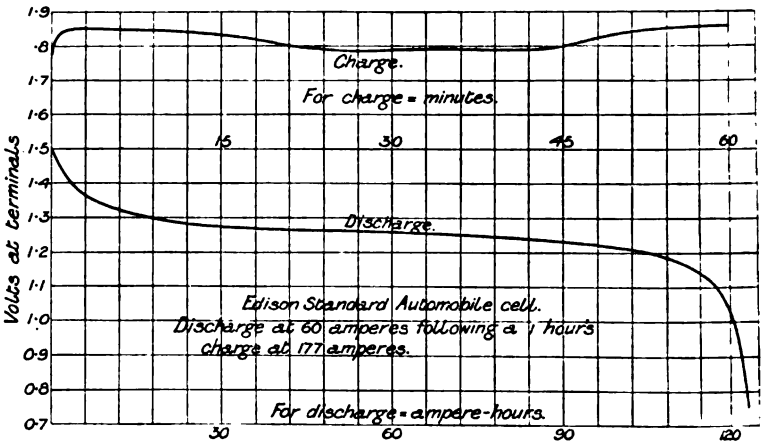

Fig. 4.

action arising when the active materials have been more or less changed by the ordinary discharge. The curves given in Figure 6 indicate the extent and variation of this prolonged discharge. They were given by one of the small cells containing four pockets, two positive and two negative. The currents are small, but the indications are typical of the behaviour of larger cells.

Effect of Rest.

There are many experiments in my notebook which show that the cell does not suffer when allowed to stand discharged for fair lengths of time. A very good illustration will be given when dealing with the motor-car trials. A parallel question arises as to how far the cell can retain its charge when allowed to stand idle.

Various trials have been made, two of which may be mentioned.

A cell was charged fully and allowed to stand 48 hours before discharge began. It then yielded 155 ampere-hours = 91 per cent. of the full discharge.

Part of this deficiency is undoubtedly due to the fact that a discharge commencing immediately is enriched by the gases contained in the pockets along with the active material. The experiment just alluded to

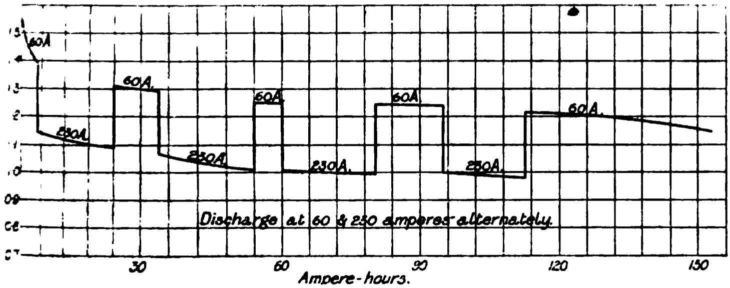

FIG. 5.

was therefore regarded as giving an idea of the immediate value of this gas effect, along with the 48 hours' action due to a short rest, such as the experiment was intended to detect. To get a better estimate of the effect of rest on the active materials, the cell was now charged up again

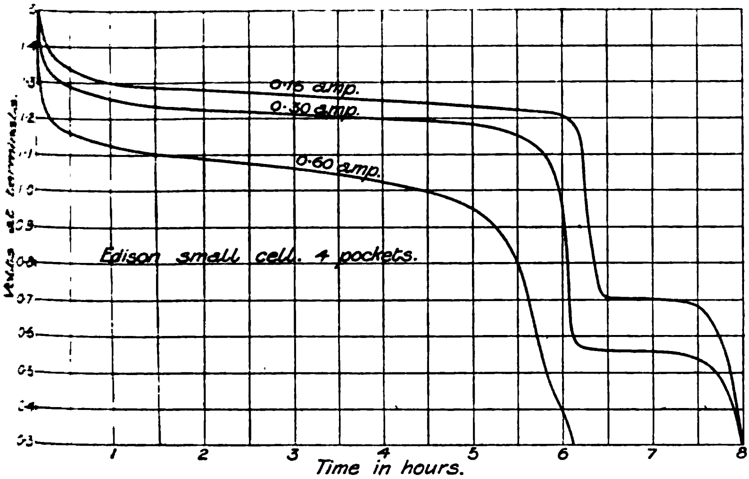

FIG. 6.

and allowed to rest for 26 days. The discharge which followed gave 124 ampere-hours.

Compared with the full discharge, 170 ampere-hours, this is equal to 73 per cent. But compared with the discharge taken after two days'

rest, we have an efficiency of 80 per cent. after 24 days' rest. That is to say, the active material lost only 20 per cent. of its charge in 24 days.

The reference here made to the effect of rest on a charged cell makes this a convenient place to say how persistent is the effect of the electrolytic gases on the E.M.F. When charging is complete the E.M.F. is about 1·6 volts, and if the cell be left on open circuit the value falls very slowly to about 1·35. It may be interesting to give a curve showing the time change in the E.M.F. when the charged cell is allowed to stand.

EFFICIENCY.

Efficiency is not very much considered in the present methods of working traction cells. A laboratory experiment is of much less use on this point than on many others. The strength of acid employed enjoins on the user the advisability of charging up when the car comes in, and of giving the cells a "buck-up" charge if much time elapses before the car is used again. This reduces efficiency. Tested on the bench, the Edison automobile cell has an efficiency varying from 66 to 50 per cent. Charged and discharged at 60 amperes, I found it to be just about 60 per cent. Charged at 100 amperes and discharged at 60, the efficiency was 56 per cent. Charged for one hour at 177 ampere

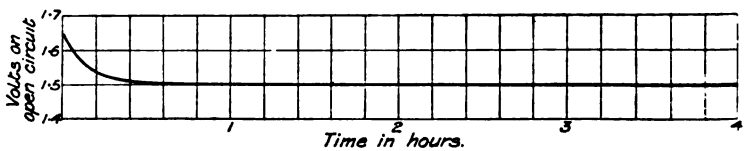

FIG. 7.

rate, and discharged at 60 amperes, the efficiency was 50 per cent. The highest figure (about 66 per cent.) was obtained at 30 amperes.

These figures are lower than would be found with good lead traction cells under the same condition of discharge following immediately after charge. But the experiment described on page 211, in which a cell was kept charged for nearly four weeks, proves that under garage conditions the Edison cell would have a much higher efficiency than the cells now used.

The point is of secondary importance only, as the total cost of keeping a car in running order is so high in relation to the cost of energy, that variations in the latter are of small moment.

OBSERVATIONS ON THE ROAD.

In considering the conclusions which could legitimately be drawn from the foregoing laboratory experiments, it was obvious that the results might be objected to on the ground that an accumulator intended for automobiles ought to do its work on the road, subject to all the irregular vibration which travelling entails. The force of this objection is obvious, and I was anxious to get some chance of watching the battery under running conditions. Fortunately, some 40 cells

arrived from America in July last, and Mr. Dick had 38 of these placed on a runabout, and gave me the chance of observing their behaviour. To this opportunity I could devote only a part of my summer holiday, and therefore the observations do not cover such a long run as is desirable. But they were long enough and varied enough to show that the laboratory results are still obtained when the work is done on the road.

A brief description of the car will suffice. It was a runabout made by the Stadebaker Company of Indiana, weighing, when fully loaded and carrying two persons, about 1,950 lbs. Of this, 700 lbs. was due to the 38 cells and their wooden frames.

Unfortunately, the battery and motor were unhappily mated, the latter being a Westinghouse 40-volt 24-ampere machine, while the cells gave an average pressure of about 48 volts. The motor was therefore overloaded all the time, and if it had been a point of importance to investigate the motor and car as well as the battery, some changes would have been necessary. But as the battery could, by careful observation, be tested independently, and as time was not too plentiful, the car was accepted as it stood.

It is not necessary here to describe any of the mechanical details. The controller had four stops with four speeds, but the first and second were hardly ever used except momentarily.

It remains now to state the results of the tests. The form in which this is done is of some importance, because it ought to deal with the battery side of the investigation: traction questions proper are subsidiary. A brief statement will clear them out of the way.

Tractive Effort.—On good level road the speed was close to 14 miles per hour, and the power about 1,920 watts, which is practically equal to 2,200 watts per ton. These figures indicate about 79 lbs. per ton for the tractive effort. Allowing for the motor efficiency, and putting it at 85 per cent. (probably not so good because of overloading), the tractive effort is 67 lbs. per ton.

The work appears to be about 135 watt-hours per ton-mile, a higher figure than is usually taken in America. This is not astonishing, considering the want of balance between battery and motor.

Cost of Power.—Fourteen miles meant nearly two B.O.T. units. If we take the efficiency of the cells as low as 50 per cent. (it is always low in electric traction as usually carried out), the charging would be 4 units. At 2d. per unit the cost would be 8d., or 0·57d. per mile.

Turning to the battery. The programme I drew up was intended to yield answers to the following questions:—

1. Is the capacity of the cell the same when running on the road as when discharging in the laboratory?
2. Will the battery stand excessive discharge rates on the road?
3. Will it take a rapid charge and utilise it on the road?
4. Will it recover after lying discharged for some time?
5. Does the capacity change in any detectable degree by reason of the mechanical agitation?
6. What attention is required?

When the car was handed over to me it had already been driven by the battery a distance of about 400 miles. This work was done in Paris, the charging being arranged by M. Gadot. This part of the work, however, I do not describe, the purpose being to exclude all but my own work.

The following is a diary of our runs :—

Aug. 29.	Standing discharge: 159 ampere-hours.	
Aug. 30.	Paris to Versailles and back, through the Park of St. Cloud. Good climb. Run about Paris ...	39 miles.
„ 31.	Eighteen miles towards Rouen and back. About Paris...	48 „
Sept. 1. } „ 4. }	Journey to London. Car ran across Paris, then train to Havre; train also from Southampton to Waterloo. Motor overhauled at Niagara Garage, and then finished the discharge by running round London. At Southampton the battery had to be partially discharged through wire	29½ „
„ 5.	London to Northampton, stopping at Dunstable for a partial charge. Part of the discharge was taken next day round about Northampton	77½ „
„ 7.	Northampton to Leicester. One stiff climb at Hopping Hill	32 „
„ 8.	Partial charge at 100 A. for 90 minutes = 150 A.H. Leicester out towards Nottingham 16 miles and back; through Loughborough	38 „
„ 9.	Charge 225 A.H. Repeated yesterday's run with extension. Discharge 150 A.H. ...	} 77 „
„ 9.	Charged 1 hr. 55 min., 219 A.H. Repeated the Loughborough run ... ... Last six miles run out next morning.	}
„ 10.	One hour's charge, 150 A.H. Same run. Discharge, 107 A.H. (32 miles)	} 65 „
„ 10.	Charged 1 hr. 20 min. = 242 A.H., and started off for Northampton. Storm all the way. Wind dead ahead. Most excessive discharge	}
„ 11.	Northampton to London, with partial charge at Dunstable. Run about in London ... ... Allowed to stand discharged for ten days.	71 „
„ 20.	Charged for 1 hr., 186 A.H. Run round London	31 „
„ 29.	Standing discharge: 158 ampere-hours.	

The total distance run is 508 miles while under my control. Adding the 400 miles run before that time gives 908 miles.

It will be observed that several runs were made from Leicester. This was due to the fact that Mr. Hales, the engineer to Mr. Wathes, was kind enough to arrange that he would be ready to assist in charging just as I liked, and at any hour. Mr. Hales also chose for me the route

followed, my request being that it should be a fairly typical English road. The conditions of each run were decided not by the desire to make so many miles, but to solve one of the six questions already mentioned.

1. Is the capacity on the road equal to that found in the laboratory?

In order to answer this and some other questions, I determined to eliminate the influence of car and motor, and to record observations of voltmeter and ammeter while discharging, just as is done in the laboratory. It seemed to me that the trouble involved (travelling with watch and notebook in hand) was worth facing, and it certainly taught me a great deal which could not have been definitely known in any other way.

As will be seen in the section 5, a preliminary experiment proved that the battery had a capacity of 159 ampere-hours at 60 amperes.* The question was, would the same quantity be available on the road? From the many observations, I choose the record of September 9th as one of those most closely watched. The run was from Leicester to some miles beyond Loughborough and back, with a final run round Bradgate Park Road. Distance = 40 miles. Eighty observations of current during the 3½ hours make the ampere-hours 150.

As the discharge was not then quite complete—the volts being above 0·75 per cell—it is evident that the quantity delivered in one complete discharge was practically the same as that found in the laboratory.

2. Will the battery stand excessive discharge rates on the road?

The original intention was to allow this to be determined by choosing stiff gradients for the car to negotiate. Accidentally however, and most unpleasantly, we had a better test than that. The return journey from Leicester to Northampton was commenced in the afternoon of September 10th, the day of the great cyclonic disturbance which spread over England and the West of Europe. That 32-mile run will not easily be forgotten. My ordinary observations were impossible; recording was a failure. But I mentally noted that the current on the level rose to 55 or 60 amperes instead of 40, the wind being dead ahead and roads greasy. On the slopes the current was frequently 90 and 100, and on one hill the index passed out of my sight, and must therefore have been momentarily more than 150 amperes.

The journey took 4 hours, as compared with 2·5 hours on our outward course. The last 6 or 7 miles were covered at a slow pace, and an interesting point crops up in that connection. Although I could not make a written note of the instrumental readings, I kept a pretty constant eye on the ammeter. While these data were fresh in my mind I calculated the discharge from the cells, and made it close to 190 ampere-hours. I regard this as a figure which errs on the side of deficiency rather than excess. If it be asked how this excessive

* This is somewhat lower than I found in the laboratory. Detailed examination of the thirty-eight cells proved that two cells were of decidedly low capacity—probably from the beginning. This would account for the deficit.

quantity could be obtained, the answer must be found in that extra delivery at lower voltage, which is shown in Fig. 6.

For many purposes this low-pressure discharge is useless, but for an emergency like that of this stormy afternoon it is a great consolation! It helps to carry the car home, although not counted in the normal capacity of the cell. It is noteworthy that the cells deliver the normal current with this lower voltage for quite an appreciable time.

3. Will the battery take a rapid charge (say one hour) and utilise it in discharge?

Several experiments of this sort have been recorded. A one-hour's charge was tried at Leicester. Unfortunately the supply station belonging to Mr. Wathes was in a state of transition, but his chief engineer, Mr. Hales, took considerable trouble in giving us special facility; 150 amperes was the maximum current we could get at the time, owing to the unfinished state of the new building and machinery.

The cells received 150 ampere-hours in the hour, and in the subsequent run delivered 107 ampere-hours = 71 per cent. of the charge.

This is exactly the figure found in the laboratory test (page 209), and also in the standing discharge test described in (4) and (5). From these three experiments it is clear that with currents of 200, 175, and 150 amperes continued for 1 hour each, the cell absorbs about 70 per cent. of the charge. I have not had facility for trying a still higher current, but it seems probable that the same proportion would hold good even with a higher current.

In Leicester, as in London, the run obtained from a one-hour's charge was quite satisfactory.

4. Will the battery recover after standing discharged?

The car was run about until its speed, and also the voltmeter, indicated that we were on the final slope of the discharge curves. The car was then allowed to stand ten days in the discharged condition. At the end of that time it was charged as follows:—

For 44 minutes	at about	200 amperes	= 156	ampere-hours.	
For 16	” ”	120 ”	= 30	”	”
	Total = 1 hour's charge		= 186	”	”

The car was then run round London and covered 31 miles, yielding 134 ampere-hours. This figure for the discharge was found by numerous observations taken during greater part of the run, combined with less numerous readings for the rest of the time. The efficiency is $\frac{134}{186}$ = 72 per cent.

From these data, it is obvious that the behaviour of the 38 cells after ten days' idleness in a discharged condition is very similar to that observed in the laboratory when quite new, and also very similar to that observed at Leicester under high charging rate.

It was thought that the combination of harsh treatment due to standing discharged followed by excessive charging current would prove specially trying, but the cells behaved very well even under these circumstances.

The test now recorded was followed by the final test on capacity as

recorded under (5), the two tests taken together giving a decidedly affirmative answer to the question now under discussion.

As the question respecting the wisdom of leaving a discharged cell idle is one of great importance, I will make one other remark. No injury appears to arise: the cell works as well after as before. But it is advisable to charge for a longer time after such an idle time. The chemical actions—the absorption changes—are a little slower than usual. Or perhaps it is more accurate to say that a greater proportion of active material is in need of restoration by the charge.

5. Does the capacity change in any detectable degree by reason of the mechanical agitations due to running?

Accumulators used for automobiles always deteriorate in capacity after a longer or shorter time. Roughly speaking, even a good battery of the lead type shows a diminished capacity after about 600 miles run, even by the crude test of miles per charge. Such a test must always be crude, because of the influence of the road, wind and gradient on the distance covered, even while the battery is still fresh.

As other duties prevented me taking charge of the car for more than 16 days, with no possibility of running anything like 1,000 miles, it was necessary to arrange for an accurate test of capacity, at the beginning and end of the trials.

A standing discharge was therefore taken at Paris on August 29th, and gave 159 ampere-hours. This is slightly less than that found for a single cell in the Polytechnic laboratory, but on examining each cell two were found to be decidedly low, and these two brought down the pressure to the final limit rather prematurely. However, as this figure was to act merely as a standard of comparison for a similar final test, it was accepted, with all the disadvantage of two somewhat inferior cells.

On September 29th, after running 508 miles, the final standing discharge was taken, and gave 158 ampere-hours.

In these experiments the errors of observation may exceed 1, but do not rise to 2 per cent.

The result may be regarded as showing that the capacity remained intact during the 500-mile run.

Remembering that there were two cells in the 38 which were obviously low, probably from the beginning, it is doing no violence to accept the capacity as normal at the end of my trials, and therefore at the end of something like 900 miles run since they were put on the car. Fig. 8 gives the discharge curve. The observations at Paris and at London are indistinguishable on the scale to which this curve is drawn.

Attention Required.

To practical men this is a most important point. They have not generally done justice to accumulators, because they have been unwilling to give them that unceasing examination which is devoted to the other parts of their mechanism. If the Edison cells needed more attention than that now given to lead cells, the need would be an objectionable feature to the men who have most to do with them. It was for this reason that I was so anxious to add to my laboratory work a series of trials from the garage point of view.

For example, the laboratory could never decide one most simple question. The terminals and connections of the new cell cannot be "burned" in any way comparable with the method adopted for lead cells. Would the mere surface contact and screw-nut adopted by Mr. Edison make a lasting connection? Laboratory trials were useless for answering this question, even though it was obvious that the design of the terminal was exceedingly good from the mechanical standpoint.

However, my 500 miles on the road were sufficient to test them; not one of them failed or became weak. Not one of the terminals proper had to be touched from the beginning to the end of the run. We had rough roads and rough weather, so that the motor was seriously overloaded, and the car was so strained that it had to go into serious repair as soon as our run was finished, but the battery and its terminals endured it all. I was especially pleased to see that in the last charge but one, with a charging current of 200 amperes, the contacts were still so good that not one of them became unduly warm.

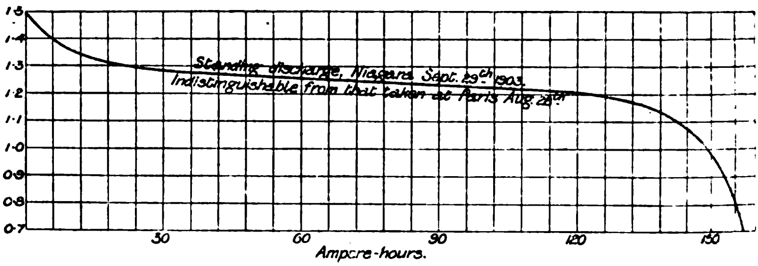

FIG. 8.

Considering what they had gone through, this was a very good testimonial.

Another point about which I had some misgiving, and one that had been mentioned in the American papers, was the question of frothing. It was said that in charging, the evolved gases caused so much frothing that the liquid would soon be run out at the vent hole.

During my laboratory experiments, extending over two months' continuous work, frothing occurred on two separate occasions. But on each occasion it lasted for about one minute only. In both cases it occurred at the end of a long charge.

On the road frothing occurred with one or two cells on two occasions. Even these did not persist, and their evidence was rather in favour of the result being accidental. It is true that on the Continent I came across a cell which was said to froth rather persistently. But this probably arose from a very simple fact. A workman is very apt to treat the one kind of accumulator as he would the other. I found one of them even using oily waste to polish the cap which covers the vent hole. It is obvious, however, that many kinds of grease will be objectionable, seeing that with the alkali they readily form soap solution,

with a consequent tendency to froth. Soap, grease, and all other colloids ought, of course, to be excluded, and are excluded rigorously from the cell.

As the thirty-eight cells on the car were practically free from any degree of frothing worth mentioning, although they were put together by men who had never seen the cell before, and as this agrees with my own experience in the laboratory, I think that the objection made on this ground cannot be substantiated.

The point which requires attention, and which cannot be neglected with impunity, is the necessity for adding distilled water from time to time. As far as my own experience went, this was needed after about five or six chargings. This meant after each 160 to 170 miles run with our car. The frequency of the water addition cannot, however, have any settled relation to miles run. It depends on the number of times the cells are charged, and especially if overcharged. As different cars equipped with variable relative weight of battery run different distances on one charge, it is desirable to get this matter put into the right form at once. The men working at garage charging stations are apt to interpret everything in miles.

Life.

Respecting life, there is the general favourable tendency of the evidence already adduced. The cells used in the car had not changed by a detectable percentage of their original capacity at the end of my contact with them. That is the most direct testimony I can offer at present. Chemical examination is proceeding, but has not as yet reached a stage at which I can add to the present knowledge. The chemical changes may be summed up in the following equation—

$$\begin{array}{ccc} \text{After charge} & & \text{After discharge} \\ \left\{ NiO_2 \;\middle|\; KHO \;\middle|\; Fe \right\} & \text{becomes} & \left\{ NiO \;\middle|\; KHO \;\middle|\; FeO \right. \end{array}$$

But it is better to write the equation in a manner which, though less simple, will be more in accordance with the practical requirements. Thus:—

After charge

$$n \,.\, NiO_2 \left| \begin{array}{c} KHO \\ 12H_2O \end{array} \right| m \,.\, Fe$$

After discharge

$$\begin{array}{r} (n-p)\ NiO_2 \\ p\,.\, NiO \end{array} \left| \begin{array}{l} KHO \\ 12H_2O \end{array} \right| \begin{array}{r} (m-p)\ Fe \\ p\,.\, FeO \end{array}$$

If I am asked my opinion as to the probability of life, the reply is definite enough. Having had these cells under close observation now for some months, I believe they will live in working order for much longer time than is usual. How much longer I cannot say, but I look forward with some confidence to such a duration as will make the Edison cell a permanent and valuable addition to the resources of electrical engineers.

The President.

The PRESIDENT: The business we have before us to-night in the first place is the discussion of Mr. Hibbert's paper. As Mr. Hibbert wishes to make a few remarks, I shall call upon him to do so before Dr. Fleming opens the discussion.

Mr. Hibbert.

Mr. W. HIBBERT: What I propose to say first of all is by way of addition, and is with regard to an improvement effected in the cell that I described at the previous meeting. During the summer, in my testing I found that the cell which I had under test was not balanced, one of the plates having a greater capacity than the other. That suggested an obvious improvement, and I wrote to Mr. Edison about it. Subsequently I had a letter from America to say that an improvement had been effected. That statement had been made to me at the time of the previous meeting, but I had rigorously determined that I would say nothing at that time which I had not myself confirmed. In the interval I have in part confirmed the results obtained by Mr. Edison with that cell. It is a cell that he calls a half-sized cell; but it is rather more than that, as there is a rearrangement of the plates. Six negatives and twelve positives are included in the cell. Its height and breadth are the same as before; its thickness is 2·5 inches. Mr. Edison sent me some curves, and I should like very hastily to sketch them on the blackboard, and to intimate how far I have confirmed them.

Discharge Current in Amperes.	Ampere-Hours.	Average Volts.	Watt-Hours.	Watt-Hours per lb. of Cell.
20	146	1·25	185	14·6
40	146	1·20	175	13·7
60	150	1·15	172	13·5
80	150	1·10	165	13·0
100	146	1·03	150	11·8

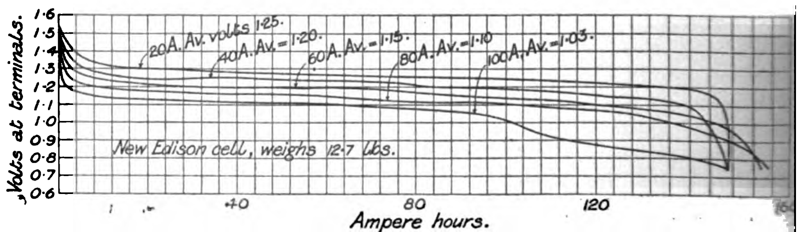

FIG. A.

This afternoon, after charging the cell which was sent over to me, I discharged it at 60 amperes. My potential difference is just a trifle higher than Mr. Edison's all the way along to the point at which I

Mr. Hibbert.

stopped, and then I was at the figure 125 ampere-hours. Other discharge rates have since been verified. I have therefore confidence in saying that the behaviour of this new cell is typified by the curves which I received from America; in other words, I regard my experiments as giving me sufficient ground for saying that the cell itself is a very decided improvement. The weight of it is under 13 lbs., being 12·7 lbs., though varying a little of course from that, according to the amount of liquid which is in it at any particular time. It gives 146 ampere-hours, and if you multiply this into the average voltages you will get the watt-hours for the particular current. These values are given in the table. Thus there is an improvement in the output of the cell per unit of weight. From the fact that the cell is likely to be more perfectly balanced than in the former case, the efficiency is not at all unlikely to be higher than it was; however, as I have made no experiments yet upon that point, I can say no more.

Dr. Fleming.

Dr. J. A. FLEMING: It is a matter for regret that this looked-for discussion on the Edison Alkaline Storage Cell has been separated by so long a time from the reading of Mr. Hibbert's paper. Events in the electrical world move rapidly, and nothing is therefore a novelty for very long.

As I was one of those, however, to whom Mr. Edison sent, through his representative, Mr. Dick, one of the new cells to test, at the same time at which several others were distributed to various physicists, I am in a position to give some of the results of original tests, which, as far as they run parallel with Mr. Hibbert's statements, confirm them, and also those of other observers such as Dr. Finzi and Dr. Soldati, who have recently reported upon the cell.

One of the 28-plate Edison cells, as described by Mr. Hibbert, was sent to me last July, but it was not until September that I was able to ask Mr. Clinton in the Pender Laboratory of University College to take up the matter and to begin a series of experiments upon it. All the measurements made on this cell at University College have been made by Mr. Clinton, with great care, by using a potentiometer for the electrical measures.

The cell when newly made requires a series of preliminary charges and discharges to bring it up to its full normal capacity, but when this was done, we found that the cell had an ampere-hour capacity of 173, and a watt-hour capacity of 212 when discharged at a mean current of 30 amperes. The cell weighs 17·8 lbs., hence this corresponds to about 12 watt-hours per pound of fully charged cell, the voltage of the cell when discharged being about 1·25.

Our experiments at University College were directed to ascertain, as far as could be done with one single cell: 1. How the cell was affected by abnormal rates of charge and discharge. 2. If high discharges brought about any permanent loss of capacity. 3. If high discharges brought active material down the pockets. 4. If any evidence existed of sensible local action between the active material and the supports.

As regards the first question, we went on gradually increasing the discharge rate from 30 up to 100 amperes, and finally took on one occasion a discharge of 380 amperes out of the cell falling to 180. In

Dr. Fleming.

all, we have given this first cell 20 charges and discharges, excluding the preliminary ones, and these have alternated with periods of rest in which the cell has been left sometimes standing charged and sometimes standing completely discharged. We found, as others have done, that the ampere-hour and watt-hour capacity of the cell diminished as the mean discharge current increases. The following table and diagram give a summary of the results :—

SUMMARY OF RESULTS ON NEW EDISON CELL,

September, 1903—January, 1904.

The cell in each case was discharged down to 0·8 volt on closed circuit except in discharge No. 10, where initial voltage was 0·7 volt and final 0·3 volt.

No. of discharge.	Mean current.	Mean P.D.	Max. current.	Min. current.	A.H.	W.H.	Previous charge in A.H.	Average charging rate.
1	30·6	1·224	32·0	22·6	173·0	212	900	30
2	30·0	1·214	32·0	19·0	173·0	210	660	60
3	31·9	1·208	33·0	20·0	159·5	193	274	60
4	28·7	1·216	32·0	17·0	168·5	205	269	60
5	51·4	1·179	57·0	31·0	155·5	183	262	60
6	60·5	1·192	69·0	36·0	145·0	173	225	100
7	72·9	1·147	80·0	41·0	142·0	163	225	100
8	91·5	1·117	112·0	62·0	143·5	160	230	100
9	93·5	1·161	116·0	60·0	154·0	178	237	100
10	266·2	0·49	375·0	170·0	115·5	57	245	100
11	40·0	1·197	42·0	24·5	150·0	179	281	97
12	34·0	1·211	36·0	21·0	130·0	158	184	92
13	23·0	1·231	24·0	13·0	143·0	176	237	95
14	29·9	1·234	30·0	17·0	142·0	175	315	105
	2 months' rest (charged).							
15	11·4	1·273	11·6	8·5	141·0	179	283	105
16	45·0	1·200	45·0	45·0	154·0	184	390	80
17	30·0	1·245	30·0	30·0	159·0	198	436	32
18	30·0	1·249	30·0	30·0	161·0	201	225	60
19	30·0	1·245	30·0	30 0	160·0	199	336	60

At end of thirteenth discharge cell was short-circuited for 16 hours.

It will be seen from this table that these high discharges do not permanently affect the capacity ; they lower it temporarily, but with a few more normal charges and discharges, the capacity comes nearly up to its original value.

We found, as Mr. Hibbert and others have done, that the cell has a remarkable power of taking up its charge in a short time. This particular cell can be charged at the rate of 100 amperes in 2¼ hours, or even 200 amperes in 1½ hours, and yet show an ampere-hour efficiency of as much as 70 per cent.

Dr. Fleming.

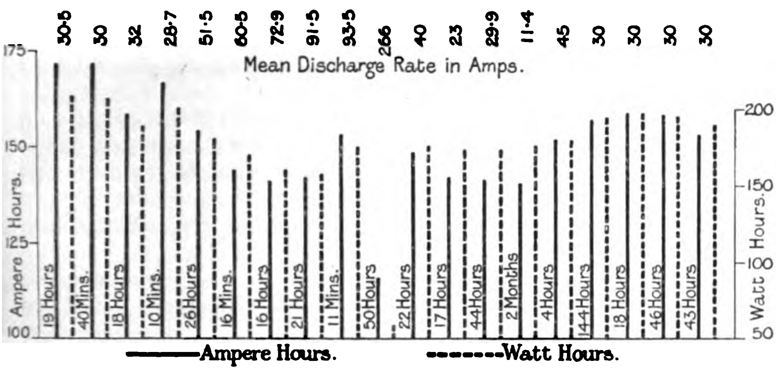

FIG. B.—Record of Tests made on a new Edison Cell at University College London, September, 1903—January, 1904.

To allow the cell to stand discharged after taking a heavy discharge does not appear permanently to reduce its capacity at the normal rate.

In the next place, as regards the removal of active material after giving the cell 19 or 20 heavy discharges, the liquid contents were removed after shaking well, the cell was washed out and the small amount of black deposit found as a precipitate was filtered off and weighed. This weight was found to be 1·4 grammes after four months' use of the cell. This deposit was analysed in the Chemical Laboratory with the following result:—

Carbon	...	22 per cent.
Iron estimated as Ferrous oxide	...	27 „
Nickel, estimated by difference	...	51 „
		100

On the other hand, all of this is not active material brought out by use, because from a perfectly new cell we washed out about one-sixth part of a gramme of deposit. Hence, it appears that after treating the cell about as badly as we could for about four months, the loss of active material from 28 plates was very inconsiderable.

Thirdly, as regards local action, we all know that in the case of the lead cell there is a considerable amount of local action between the active material and the lead support. I was anxious to see what evidence there was of any such action in the case of this nickel-iron cell. An experiment was accordingly tried with a number of pieces of bright iron. These were put into a 20 per cent. solution of caustic potash, and on the end of one of these pieces was placed a small quantity of the oxide of iron as used in the Edison cell, and on the end of another plate a small quantity of the oxide of nickel. A third plate was partly oxidised by rusting it. These plates, together with a piece of bright sheet nickel, were left in the caustic potash for two months. There was no evidence of any chemical action at all on the iron, and it remained perfectly bright in this solution for two months.

Dr. Fleming.

A similar experiment was tried with a piece of lead, placed in dilute sulphuric acid, and a pinch of peroxide of lead, placed on one end. In the course of a few days the bright lead was heavily covered with sulphate of lead, due to the local action.

The oxides of nickel and iron are also insoluble in the 20 per cent. solution of caustic potash. There are only some seven common metals of which the oxides are insoluble in this solution, and of these the iron oxide and nickel oxide, as prepared by Edison, are almost the only two that can be commercially used. These metals are iron, nickel, cobalt, copper, manganese, bismuth, and silver.

This absence of local action seems to be a very important point, as it enables extremely thin supports to be used to carry the active material.

The whole subject of the oxidation of iron is one that is full of practical interest, and has hardly received from chemists the attention that is due to its practical importance.

Mr. Edison's important discovery in connection with this cell appears to have been that of finding how to prepare a particular form of oxide of iron which can be reduced, and oxidised again in a caustic potash solution by nascent hydrogen and oxygen.

In contrast with the lead cell, the electrolyte in the Edison cell takes no part in the chemical action; it merely conveys oxygen to and fro, and therefore there is no change in the density of the electrolyte during charge and discharge, and no necessity to do anything but to add distilled water occasionally, to make up for evaporation.

There is an immense gain in getting rid of dilute sulphuric acid as the electrolyte, and thereby enabling us to use a more mechanical and lighter form of metallic vessel as the containing cell made of a material which is quite unacted upon by the dilute caustic potash, in place of the fragile ebonite cell encased in wood necessary with the acid.

In taking efficiency tests of this 28-plate cell, 14 positives and 14 negatives, there is a difficulty in determining when the charge is complete, because the electrolyte boils nearly all the time.

I have recently had sent to me a later form of half-size Edison cell, by Mr. Dick, which is still under test, and there are in this cell 12 positives and 6 negatives, and the result of this is said to produce less wasteful boiling during charge, and to increase the capacity for the same weight of cell by 50 per cent.

I am well aware of the caution necessary in speaking of the performance of a secondary cell solely from the results of tests on a single cell. I have not yet had the opportunity of testing cells in actual automobile work, and therefore I am unable to speak of them under this head.

As far as regards laboratory tests, it appears that the notable advantages of the cell may be summed up by saying, that whilst its watt-hour capacity per pound is not markedly greater than that of many light weight lead cells in use, there seems to be clear evidence that the durability of the plates is greater and the liability to disintegration or deposit of active material is considerably less than in the lead cell, and that local action between active material and the supports is practically absent

and also the cell will in consequence of the absence of local action bear being left lying idle in an uncharged state without permanent injury, whilst it also has enormous power of taking up and giving out charge without permanent injury. Dr. Fleming.

These are all very good points, to which may be added, that without doubt the arrival of the Edison cell in the arena of practical work will stimulate improvements of existing types of lead cells. It is not a little curious that only four years ago a very eminent authority on storage battery chemistry, Mr. Wade, read a paper in which he classified all possible secondary cells into lead cells which were practical, and others which were not. Since that time Mr. Edison has been at work, and there seems clear evidence that he has laid the electrical engineering fraternity under a fresh obligation, by the invention of this new nickel-iron cell.

Mr. E. J. WADE: As Dr. Fleming has kindly made a reference to myself, I will take that point to start with, and say that that classification of mine, made four years ago, was, I think, justified then; but I quite agree now that the subject looks to be on a rather different footing. All the members of the Institution who, like myself, are interested in storage batteries, owe a great debt of gratitude to Mr. Hibbert for having relieved us from the terrible alternations of hope and fear that we have been going through these last two or three years, owing to the reports in the non-technical press. It is really quite a relief to know that the lead-battery makers have not yet to put up the shutters, although there is a formidable rival in the field. We have had such a number of practical details both from Mr. Hibbert and from Dr. Fleming this evening, that I feel rather afraid to raise any theoretical question; yet I think perhaps there are some points on which we should like to get a little further advanced. Mr. Hibbert's paper deals with the cell almost entirely from the outside. He has connected wires to its terminals, and measured the ingoings and the outcomings, and given us most valuable data; but, figuratively speaking, I should have been glad if he could have got inside the cell and pulled it to pieces, and told us a little more of the why and the wherefore of some of these new points about the cell which seem to mark it off so very much from the lead battery. Mr. Wade.

With reference, for instance, to Figure 2 in Mr. Hibbert's paper, I should like to ask him what he considers to be the causes which determine the characteristic curves of discharge that he gives there. You will see that in general these curves very closely resemble the curves for a lead storage battery. First of all there is a rapid fall for a short time, and then there is a long gradual fall covering most of the discharge of the cell, and then again there is a very rapid fall almost down to the vertical. Mr. Hibbert, in a paper which he read before this Institution in 1892, in collaboration with the late Dr. Gladstone, "On the Cause of the Changes of E.M.F. in Secondary Batteries," ascribed all these potential changes to the strength of the electrolyte. Here we have a cell in which one of the great points is that there are no variations in the strength of the electrolyte, and yet we are getting almost similar curves. It seems to me that that is a point which wants a little

Mr. Wade. explaining. For myself I rather fancy that in both cases the first rapid fall of potential is due to the peroxydised products in the cell—probably in the active materials themselves; and that the final rapid fall of potential is due to the rapid increase in the specific resistance of the active materials. The intermediate fall, I should think, is partly due to changes in the active materials, and partly to the slight variations which there must be in the concentration of the electrolyte in the pores of the active material, although its average value remains the same. Still, I think that is a point that should meet with a little more elucidation.

As to another point, which is of more practical interest to us, namely, the remarkable way in which the potential curves are maintained at very high discharge rates, I do not notice that Mr. Hibbert has given any specific explanation of that in his paper. I take it as fairly obvious that here we have an effect due to the electrolyte not varying in strength, as it does in a lead cell. Some experiments that I have made on lead cells rather seem to confirm that. For a long time I have had the idea that if one could get a more porous active material one would do away with the reduction of capacity on high discharges, and bring about results more akin to what we see the Edison cell furnishes. I have lately prepared some active material with a very high porosity—from three to four times the ordinary porosity in lead cells; and with these I have got very much the same results on rapid discharges taken at a one-hour rate, as appears in the Edison cell. This goes to show that it is the exhaustion of the electrolyte in lead cells that brings down this output at high discharge rates, and that its absence enables the output to be maintained in the Edison cell. I think that while we all accept the results of Mr. Hibbert's actual tests, some of the inferences which he implies with regard to lead cells are not to be quite so implicitly adopted. I see one or two gentlemen here who know a good deal about lead cells in practical working, and I should rather imagine they will join issue with Mr. Hibbert over some of his comparisons; so I will not delay the battle any longer.

Mr. Joly. Mr. H. L. Joly: Since the beginning of December, I have had one of these "28-plate" cells in my laboratory, and I have made a series of some fifty charges and discharges, the results of which are fully in accordance with those obtained by Mr. Hibbert and others; from them I have plotted the capacity curve, and calculated Peukert's coefficient, the value of which came to 1·1 taking 150 amperes as the rate of the one-hour discharge, and to 1·09 if that rate be taken at 160 amperes. This value is the lowest on record as far as I know, leaving all the lead cells far behind. As to the internal working of the cell, I thought it would be interesting to investigate the comparative behaviour of the iron and of the nickel-oxide electrodes, by means of an auxiliary electrode. Cadmium was tried, but the results were not sufficiently satisfactory, so we have worked regularly by taking the steel container as auxiliary electrode, as previously done by Janet. This even is not strictly accurate, as during charge the slight space between the container and its ebonite lining appears to get filled with gases. One sees by this method that the rapid drop at the beginning of the discharge is

due to the nickel plate; the same applies to the second drop, and the fact is very marked. It may be due at the beginning to gaseous polarisation, or perhaps to the existence of some unstable oxide of nickel of a higher grade than generally known. At the time of the second drop immediately preceding the flat, the iron plate shows also a small drop in E.M.F.; that is to say, the P.D. between the negative plates and the container decreases at the beginning of the sharp drop on the nickel, and rapidly recuperates as shown by the presence of a V on the curve (Fig. C). Mr. Joly.

We tried some experiments as to various charges and various rates of charge. Janet, in Paris, used 300 A.H. charges right through his experiments, and Gadot I believe charged much more. I charged at

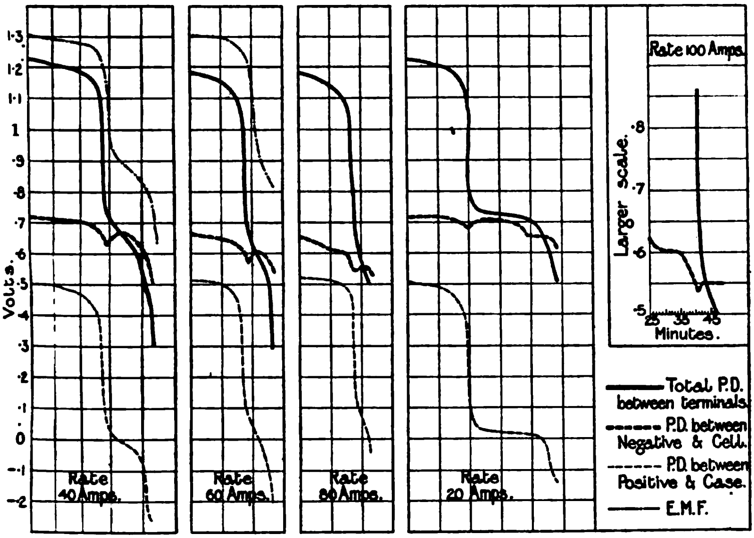

FIG. C.—Ends of P.D. Curves on Discharges at Constant Current, showing individual behaviour of Electrodes.

300 A.H. in most cases, but I found that by charging at 200 A.H. we got a much better efficiency although the capacity was smaller. We had in most cases 60 per cent. (in quantity) after charging at 300 A.H., and we got 75 per cent. with the 250 A.H. charges. One can get at the value of the charge needed by another method than measuring the E.M.F., and I think the E.M.F. measurement hardly shows the true state of affairs, as it rises long after the P.D. has become constant. Dr. Rokotnitz showed recently, in his experiments on Planté formation of lead peroxide, the value of gas analysis in investigating the oxygen efficiency of the cell. In the case of an oxygen lift cell gas analysis seems readily indicated, and we have carried out such an investigation on the Edison cell, both by absorption and by eudiometric methods. One can secure a thistle funnel on the top of the gas valve, and lead the gases into a solution of a ferrous or cuprous salt, for instance, when the oxygen left

Mr. Joly. unutilised by the nickel plates will become fixed by the absorbing solution, and the remaining hydrogen measured. If that is allowed to go on during charge until you have reached 250 ampere-hours you will notice little or no modification, but later there is a rapid modification due to the absorption of oxygen. Both the rate of evolution and the total volume of the gases were measured on a great many charges, and the rate at which they were evolved was found to vary considerably with the rate of charge, somewhat like the E.M.F. Charging at 30 amperes, the rate at which the gases were liberated at the end of 300 ampere-hours was found to be 20 litres per hour; at 200 A.H. it was only 6 litres per hour, and rose rapidly, from 200 A.H. onwards. The cause of that increase seems to be the electrolysis of the water in pure waste, without the gases chemically working inside the cell. Charging at the 100-ampere rate, the increase is much more marked, the rate got up to 54 litres per hour, nearly at the end of charge. I will send to the Secretary the curves embodying these results. In my opinion, one could by gas analysis get very interesting data towards the chemical theory of the cell; the eudiometric method is particularly suitable for that work, as it enables one to get a series of determinations all along the charge. In one case I calculated roughly the amount of oxygen absorbed by the plates during the last 50 A.H. charge, and I think the result came to just over a gramme. Another point which has been closely investigated, is the work of the cell when discharged at varying rates. A mercury resistance was arranged so that the cell could be discharged at various rates, starting with 40, then 50, then 30 up to a hundred amperes, and down again, besides lower rates as shown in Fig. D in a manner similar to what was done in Paris in 1898 by the French Automobile Club for the Concours d'Accumulateurs. The discharge corresponds to the average rate of 37·5 A.H. per hour, and the cell which I tested gave in that way a four hours' discharge, *i.e.* a capacity of some 150 ampere-hours, with an average voltage of 1·25 volts (190 W.H.). Taking for comparison a type of lead cell largely used in London for electric broughams, and weighing 10 kilogrammes, a-piece, the standard capacity of which is 140 A.H. at the flat rate of 30 amperes (specific gravity at beginning of discharge 1,260), I submitted several cells to the same varied discharge, with the average result of a discharge lasting just over three hours, under the same conditions as the Edison cell; this represents 220 W.H., the capacity in watt-hours being greater than that of the Edison cell.

Now, as to the great amount of formation which has to be given to the cells. Lead cells, when the plates are purchased dry and submitted to fairly long journeys, have to undergo a similar treatment, and it is a process which takes a fairly long time. Nickel-iron cells, however, seem particularly affected by transport when dry. Herr M. U. Schoop, of Cologne, told me in December that a Jungner cell which he had tested at Kneippbaden (Sweden), on being tested in his laboratory in Cologne showed a capacity very sensibly smaller through having been sent dry. That cell is on the same principle as the Edison, and as a matter of fact I believe the Jungner patents were filed here before the Edison patents. The figures obtained in Cologne are similar to those

given by the Edison cell, though slightly smaller. Like the new Edison cell described to-day by Mr. Hibbert, the Jungner cell is asymmetric: it has five positives and four negatives. The material is Mr. Joly.

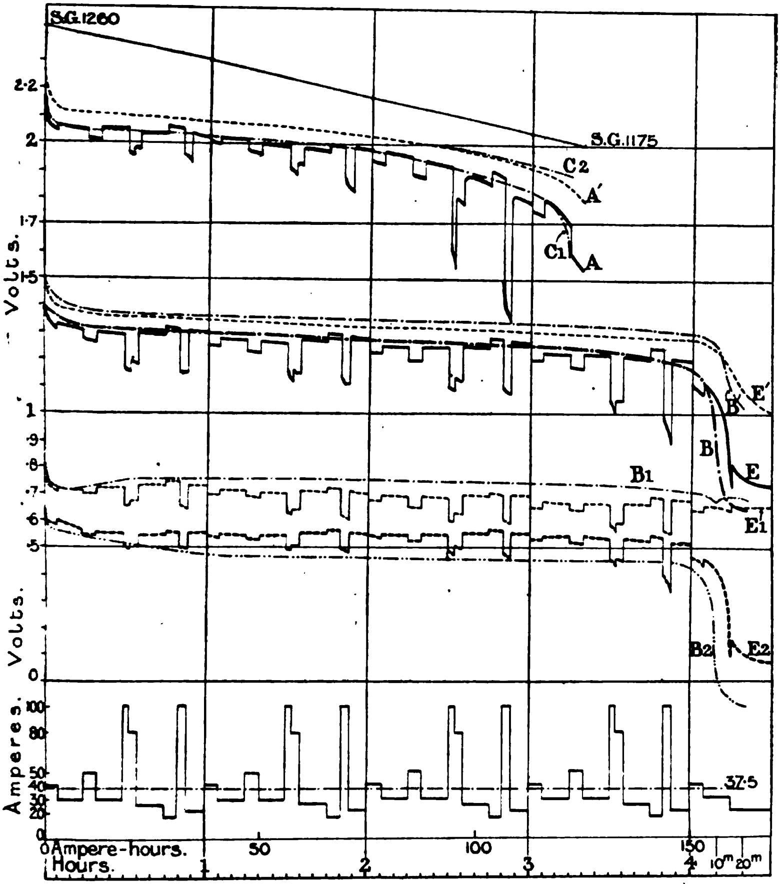

FIG. D.—Edison Cell and "Electricia" (Contal) at varying rates (37·5 A.H. per Hour).

Contal	A	P.D. Contal cell at varying rates.	C_1	Ditto at flat rate 37·5 A.
	A′	E.M.F. " " "	C_2	E.M.F. " "
Edison	E	P.D. Edison cell at varying rate.	B	Ditto at flat rate.
	E′	E.M.F. " " "	B′	" "
	E_1	P.D. Negative electrode to container.	B_1	(−) to cell.
	E_2	P.D. Positive " "	B_2	(+) "

enclosed in pockets, but the construction of the cells as made in Sweden is far less mechanically perfect than that of the Edison cell.

Respecting the mileage of lead cells, Mr. Hibbert says that, "Roughly speaking, even a good battery of the lead type shows a diminished capacity after about 600 miles' run." It is quite possible

Mr. Joly. that it does show a diminished capacity, but, unless the cells are of a poor type, that does not mean that the battery is not fit to be used any longer. Plenty of cells have passed through my hands which have worked over 2,000 miles, driving fairly heavy carriages in London, the run per car averaging 28 miles per day (though as high as 59 miles has been recorded more than once), thus doing some 3,500 to 4,000 ton-miles before being washed—that is to say, before the diminished capacity indicated such bad internal state that the battery had to be treated. I do not think that such a bad performance, especially considering that a lead cell endowed with that life and a capacity of

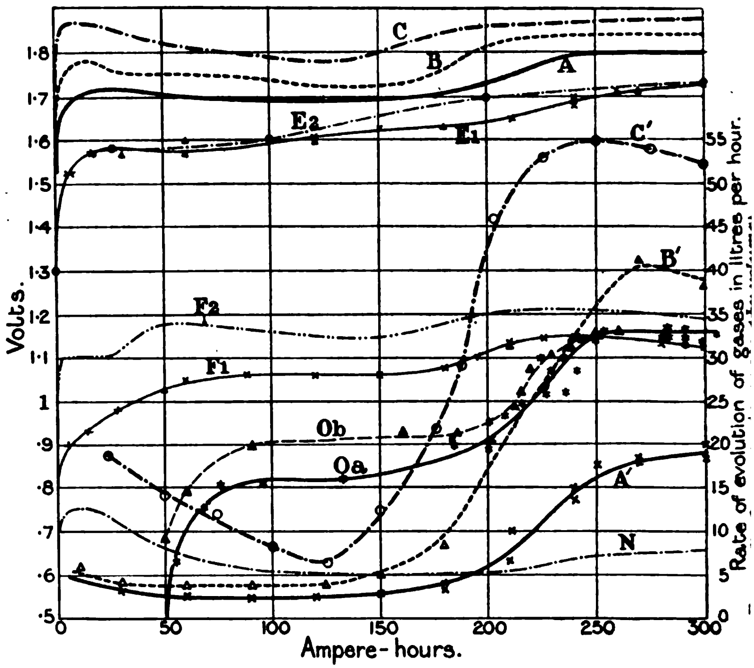

Fig. E.

135 to 140 A.H. can be bought in quantities for twenty-eight to thirty shillings. As to efficiency, I would add that I found this to remain practically constant at the varying discharge rate or at the flat rate corresponding to it, both in the case of the lead cell and in that of the Edison cell.

As to shedding, the performance of the Edison cell is certainly extremely satisfactory, but there is a battery on the market, in which the plates are made up of rods of active material wrapped up in asbestos jackets, which has also proved practically free from shedding. I have seen in Paris, in May, 1902, such a battery. I was told on creditable evidence that it had driven a car over 6,000 kilometres

Mr. Joly.

Some of the cells were opened in my presence, and they were as clean as when first put together. I will say nothing respecting their capacity, because I did not test them. Four such cells, however, have been in use in my laboratory, in 1901–1902, for over a year, and very often doing heavy duty, and at the end of that time they had within 7 per cent. of their original capacity, which with the hard treatment they have been put to is not so very bad—for a lead cell. I think this covers all I had intended to say, and, in conclusion, I think there is still considerable hope and room for the lead battery.

Communicated.—Since the discussion I have calculated most of my eudiometric data, besides obtaining further observations, and the chief results are embodied in Fig. E, showing the variations in the rate of evolution of the gases at various rates of charge, with the corresponding variations in the percentage of oxygen present in the gases.

Mr. Cooper.

Mr. W. R. Cooper: This paper is interesting from two points of view—one from that of the cell, and the other from the point of view of automobilism. Mr. Hibbert gives some experiments on an electric runabout. Unfortunately they are not as interesting as they might be, because the runabout seems to have been very badly designed for the work, and was much heavier than is usual. This runabout ran only about 34 miles with one charge, which is very little for that weight. However, the author seems to have proved most of his points, except perhaps that dealing with the effect of heavy rates of discharge. Such a question cannot be decided by a single experiment. Apart from that, the question of excessive discharge depends rather on the basis on which it is considered. If one takes the weight of the cell as the basis, then certainly the discharges were heavy; but the tendency in automobile work is to diminish the weight quite as much as, or more than, to increase the capacity. Therefore, I think, one should preferably take the capacity into account as a basis, and consider the discharge from that point of view. If one does that, the discharges are not really as heavy as they might be, and I do not think they can be called excessive. However, Dr. Fleming has dealt with the point of excessive discharge, and so perhaps one need not consider it further.

The extra discharge at low voltage is interesting, and may be useful. Mr. Hibbert says that if it had not been for this discharge he would not have got home at all on one occasion. I am not quite sure whether he really did rely on that extra low voltage discharge or not, because if you refer to Fig. 6 you will notice that with the high rate of discharge the extra little bit of capacity seems to vanish. I should like to ask Mr. Hibbert whether there was a voltmeter on board, and if he can give us any information from that.

In mentioning the effect of temperature on the E.M.F., Mr. Hibbert ascribes the effect simply to a change of the internal resistance. That explanation seems unlikely, because the capacity must principally depend on the consumption of the active material, and would not be affected very much by resistance. Generally, raising the temperature increases chemical action, or at least increases the rate of chemical action, and therefore I do not see why raising the temperature of a cell should not raise the rate of electro-chemical reactions and have the

Mr. Cooper.

same sort of effect. Mr. Hibbert also mentions the effect of short circuits, and says that he gave a long charge after a short circuit. Would Mr. Hibbert mind giving particulars of that long charge?—for instance, as to the current used and the ampere-hours. As to the efficiency, that unfortunately is low. One would expect it to be lower the lower the voltage of the cell, but at the same time it seems to me that the quantity efficiency is a good deal lower than it should be, considering that the cell is said to be free from local action. In giving details as to the car, Mr. Hibbert takes the efficiency of the motor at 85 per cent., which seems a high figure for that size motor, more particularly as there is presumably some gearing.

I join with Mr. Wade in being sorry that Mr. Hibbert has not touched upon the theory of the cell. He has been so very much concerned with the theory of lead cells that I rather expected he would say something in connection with the theory of these cells. I should like to ask Mr. Hibbert whether he has been able to verify the composition of the oxides. The oxide of nickel, as far as I know, has been regarded as more or less hypothetical up to the present, and apparently the oxide of iron is something quite special that we have not been able to get at before. Could Mr. Hibbert give us any idea as to the determination of the E.M.F. from thermo-chemical data? Since the caustic soda is re-formed as quickly as it is decomposed, it may be regarded merely as a carrier without effect on the E.M.F. The E.M.F. is then due to the difference in the heats of formation of Fe to FeO and NiO to NiO_2. NiO_2 has so far been looked upon as hypothetical, and its heat of formation from the lower oxide, as far as I know, is unknown. Taking the heat of formation of ferrous oxide as 68,090, and the E.M.F. as 1·3 volts, then the heat of formation of the NiO_2 from the lower oxide would be only about 8,000 calories. This is very small, more particularly as the passage from NiO to Ni_2O_3 requires about 60,000 calories, and it might be thought that a further oxidation would require still more energy. This is not always the case, however—as, for example, in the oxidation of water to H_2O_2—but the oxidation from Ni_2O_3 to NiO_2 would scarcely be expected to be so highly endothermic. But in this I am assuming that the ferrous oxide in question is like that which is commonly produced in chemical reactions, whereas it is produced electrolytically and may differ very considerably in its heat of formation as in its other properties.

Mr. Patchell.

Mr. W. H. PATCHELL: I am afraid I have found some difficulty in focussing this cell. It is about ten or twelve years since I saw my old friend Mr. Wade, and it is almost that length of time since I saw a tramcar cell or anything approaching an automobile cell. Since then I have gone in for cells which do not weigh pounds but which weigh tons, and I have found them thoroughly satisfactory. Mr. Wade mentioned one point that rather brought me back to old times. He referred to the exhaustion of the electrolyte either in the plate or near the plate. I remember when first I took up battery work we were trying to make the plates porous. We had all sorts of messes and combinations to try and mix up with the peroxide of lead or with the litharge, but none of them gave as good results in practical

working as the pure oxide; I suppose that was mainly due to local action. In those days also we did not really recognise how pure our materials had to be. I remember the first time I asked to have a really close analysis of the materials I was told, "Oh no, it was not necessary." I think battery work has improved very much, mainly owing to the greater care taken in the materials used. Mr. Patchell.

On the question of the circulation, our friend on the right mentioned Mr. Schoop. I remember Mr. Paul Schoop coming over to our laboratory and bringing with him a cell with a solid electrolyte, which was to knock all others out. The circulation was practically stopped by the gelatinous electrolyte which he used, and we not only got a higher resistance, but what we would nowadays call a lag in the discharge. In the charge the acid would not circulate properly, so that we got the plates eaten into, with the result that we got a very much shorter life from them than we got from plates which had a proper circulation of the acid. We were working at that time with narrow forks. A special battery was ordered, with forks of about three-quarters of an inch, and exactly the same plates as those which are generally used with forks of about a quarter of an inch. That battery made up with the very wide forks was one of the best batteries we ever turned out, the result, I believe, being mainly due to the better circulation. I think a great many of the batteries were spoilt in those days by the plates being a great deal too close. I find, now that we are working on a really serious scale with large cells, that one of the features of the success has been due to the wide spacing—practically something over half an inch—nine-sixteenths I suppose it would be, if you measured it up. They are all free to expand, and there is plenty of room, and if any mud does fall down it falls clear. I think our great gain there is due to the free circulation.

I quite join with you in expressing regret that none of the men who are now actively engaged in making secondary batteries are here. I have seen advertisements of English makers, and one in particular does not hesitate to use the Edison battery very freely in his own advertisements. It reminds one of a nursery rhyme that we used to learn, that the man who fights and runs away lives to fight another day. We like to have our fights in the present, so that we can all enjoy them.

Mr. W. HIBBERT, in reply: I see, sir, that I have made notes of fourteen points that have been referred to, on which I might profitably, I suppose, say something. Mr. Hibbert.

First comes the question of the formation of the cell. It will explain, perhaps, a good many lapses in my paper if I say that I left some things out because I did not know them. I did not know anything about the formation of the cell. The cell was made in America, and I knew nothing of its minutiæ. It was sent over to England without the liquid, so that the plates were freely exposed to any oxidising action of air, and all those of you who have ever heard of pyrophoric iron know what that must mean for the positive plate. The long charging operation that has to be given to the cell when it is

Mr. Hibbert.

first put into use is not, I suppose, a formation corresponding to that which may or may not occur in the laboratory when the cell is made. Of that I know nothing except that it is simply due to the fact that a great deal more chemical work requires to be done on the cell after transporting it across the ocean, because of the pure atmospheric oxidation which has gone on during the journey. Consequently I thought it somewhat irrelevant to say anything about that, regarding it as an accident. If the cells had been made in England and sent about filled with the liquid by rail, I presume that that long charging would not have been necessary.

If I may take the points in order as I noted them down, they will follow the order of the speakers. Dr. Fleming has spoken to you about the fact that after working for a certain length of time with a cell like that I described to you in November, he agitated the liquid, ran it out of the cell, and then filtered off some solid stuff which he found there, and had it analysed. I can add to the data which he gave you one or two others. For instance, I have myself done that, not by agitating the cell and pouring out the liquid, but by breaking up one cell which, in consequence of very violent behaviour, had come to grief. When I say very violent behaviour, I mean that its treatment on the London cab where it was placed was of such an order that, although it had been taken out of my hands entirely by that time, I made an initial protest against its being used in such a fashion. It came to grief, and it was then sent to me to see what was the matter. It was broken open, and I analysed the stuff which was found in the liquid. I have here the result of the analysis showing the proportions of the active material which was then found at the bottom of the cell to the whole. I found that it was rather less than 1-2,000th of the whole active material in the cell. The loss had been going on from the time I received it in Paris up to something like the third week in December—that is to say, it had done something over 3,000 miles, and at the end of that time something less than 1-2,000th of the whole of the active material had been expelled from the pockets. The proportion of graphite and of oxide of iron and of oxide of nickel that I found was almost identical with that found by Dr. Fleming's colleague and reported to you earlier this evening—that is to say, the graphite was about one-fifth of the stuff which had been ejected.

I have one or two other data, but I think I ought not, in view of what is to follow, to give you so many figures, but that I ought rather to run on with the general statements I have to make. You heard from Dr. Fleming about the experiments which he has made on the rusting of iron in alkali. I am lucky in having been an observer of an experiment that lasted for many years. In 1874, which is just thirty years from now, I joined the staff of the Royal Institution. I remember very well that amongst the things in the museum there were certain bottles which had been sealed up by Faraday probably thirty years before that. These bottles contained brightly polished steel and iron which he had immersed in alkali in order to study that very question. As I have told several people who asked me with respect to the possible rusting of the iron, the steel in those bottles was as bright on the day

Mr. Hibbert.

when we were at the Royal Institution as on the day when Faraday had put them up—that is to say, they were about as bright as could be. I take it that that is exceedingly good evidence of the fact that even over a very long time we have no reason to expect that an alkaline solution will in itself oxidise iron.

Within the last two or three years there have been some researches on the oxidation of iron, in which the previously existing theories have been challenged, and certain new contributions made with regard to it. I am pretty well assured, from all I know, that there is no reason to suspect that there will be any danger to the Edison cell from the rusting of these materials, and the consequent inherent action of the liquid upon them.

I see the next point I have is with reference to the testing of single cells. That, of course, was a possible objection up to the date at which I personally, and others as well, received only one. But on the automobile I had the chance of working with thirty-eight; these were subsequently increased to about sixty, and although I do not know the number of cells that have been distributed over Europe, I should say it must be near eighty or ninety. In view of that fact, and remembering also that all the gentlemen who have tested them have found results which are almost exactly repetitions one of the other, it seems to me that the single-cell testing objection has already fallen to the ground, and we may look upon the results already obtained with the standard cell as sufficiently representative..

Mr. Wade remarks on the fact that all the data I gave in the paper referred to external circumstances. That was simply because I knew nothing about the internal conditions. I had no chance of getting the cell as it was originally made. Up to the time of reading the paper I had no chance of examining the interior. My knowledge of the chemistry was very small—I am free to confess that—and because it was so I said nothing about it. As soon as I am in a position to speak with confidence then I shall be prepared to declare what I know, but until that time comes it would be folly to say anything. The chemical data are vague; they are vague even with reference to the oxides of nickel which have been prepared by pure chemical processes, and which are amenable to straightforward examination. I suspect that when this task of examining the electro-chemical oxides has really been carried through, we shall find that there is not one nickel oxide but two, or three, or more. I have already suggested that there is evidence of oxides higher than those indicated in the formulæ I used, or indeed in any other statement I have seen except one contained in a speech delivered by Mr. Krieger at Paris.

Mr. Wade further asks me to explain Figure 2 in my paper. The chief points in that are embodied in the curves that I put on the blackboard earlier in the evening. There is a rapid fall in the potential difference at the beginning of the discharge, followed by a comparatively flat part, and succeeded at the end by another rapid fall. These features are also observed in the discharge of a lead cell, and at the first glance it might be supposed that an explanation which referred to the one would also refer to the other. But one has to remember that that

Mr. Hibbert.

anticipation is vitiated by the fact that there is a distinctly known verified change in the one case which does not occur in the other. In the lead cell you have changes in the density of the acid in the plate at the beginning of a very rapid order, you have changes in the density of the acid at the finish of a rapid order, and you have changes in the density of the acid during the middle period which are not of a rapid order. Now changes in the density of the acid are known to be competent to produce changes in the E.M.F. of a lead cell. It is perfectly right and legitimate, therefore, to suggest that the changes in the density of the acid are themselves the sufficient cause of the changes in the potential difference. Moreover, there is one point in the behaviour of a lead cell which bears very strongly indeed on the whole of this subject. Consider for a moment the discharge-curve of a lead cell, especially the part which shows that the cell is discharged, the voltage falling rapidly. If, now, you warm that cell 5°, then, irrespective of any other change in the resistances of the materials, you will find a very material increase in the capacity of that cell and in its ability to deliver a current of the ordinary magnitude. There would be probably something like a 10 per cent. increase in the capacity, if not more. The fact that the temperature is able to produce a very large change in the coefficient of diffusion of the acid is sufficient to explain this and to support the idea that weak acid is the efficient cause of the rapid fall in the potential difference at the end of the discharge. I suppose, therefore, that I am justified in regarding the changes in the lead cell as due to local changes in the density of the acid. On the other hand we have no such changes in the density of the electrolyte in the case of the Edison cell, with the consequence that it would be folly to suggest that explanation here. I have given in the paper measurements of the resistance of the cell as far as it could be ascertained by tolerably simple experiments, and have shown that at the end of the discharge the resistance of the cell is going up very quickly indeed, and where the potential difference—not the E.M.F., but the potential difference—is falling rapidly at the finish, the resistance may be something like four to five times its normal value. That in itself would very rapidly bring down the potential difference to these values. The other curves in the paper suggest a change in the electro-chemistry of the cell at the point where an additional discharge begins. That, I suppose, will be sufficient to indicate how I would deal with the similarity of the potential difference curves and the explanation of them on different lines.

With regard to the capacity of a lead cell, Mr. Joly spoke of my quoting a 600 miles run as indicative of the time at which a lead cell would require a wash-out because of diminished capacity. I think I confess in the paper that my experience of automobiles is very limited. The figure that I gave was fortunately, or unfortunately, as the case may be, quoted after appeal to gentlemen who are engaged in that industry. My question practically was this: After what run do you expect to find an observed change in the capacity? The answers varied, but I took all the figures and gave you the average, which was further verified by reference to a well-known authority. If the mean

figure be a misrepresentation of the ordinary fact, I can only express my regret, but it was the people who use the cells in ordinary work from day to day who gave it to me. Mr. Hibbert.

Mr. Cooper has asked several questions and made some remarks about the weight of the roundabout. I had to take the latter as I found it. It was not a bit too heavy for the work we gave it to do; the wheels came off soon after I delivered it up at the London Garage, and I was very glad it had been made as solid as it actually was.

Mr. Cooper will find in the paper how I estimated the output on the day of the storm. There was a voltmeter in front of me, but I could not read it towards the end of the journey on account of the wind and the rain. Mr. Cooper makes remarks on the capacity of the cell as deduced by me, but I say that I could not read the instruments at the finish, where Mr. Cooper's question would be more especially pertinent. When I tried to estimate the output in ampere-hours of the cells during that journey, I purposely chose a figure much lower than my observations suggested. If I had given you my unbiassed opinion, I should have quoted an output of a much higher value, but I thought it the wiser thing, as I was in part guessing from an occasional reading of the voltmeter in the earlier part of the journey, to put the figure as low as I reasonably could. Similarly with regard to the 85 per cent. efficiency of the motor. I was simply trying to get an idea of the average tractive effort on our English roads. I had no knowledge of the efficiency, but I made such a guess as we all make with regard to unascertainable values.

I have no information on the possible changes produced by temperature on the active materials or the alkali except this—that the change in resistance of the potash solution with temperature is known, like most electrolytes, to be of the order of 2 per cent. per degree centigrade. Mr. Joly refers to recent researches as showing the value of gas analysis in investigating oxygen efficiency of a cell. He will find in the researches of Dr. Gladstone and Mr. Tribe a full account of the way in which this method was used for the same purpose as early as 1882.

There is hardly any other point, I think, which I have not referred to. Many things might be said, but I have found such an awful scepticism about anything that referred to the Edison cell that, as I have already declared, I will state nothing, except that which I have myself verified. The scepticism seemed to me to be uninformed and unjust, and—I make the remark now, though I did not make it then—it was unjust to the inventor of the cell in my opinion, because many of the statements that have been made in the non-technical Press, or even in some of the American papers that might be regarded as being tinged with technical knowledge, were typical, not of Mr. Edison's contributions to the electrical engineering services of the world, but of the habits of the people who write in such journals. I thought it was really unjust to Mr. Edison that statements which were at any rate worthy of some careful consideration should have provoked, or should have been allowed to provoke, such serious and unjust scepticism. For that reason I deliberately kept out of my paper many things that I had been told, and on which I had some reason to rely, but which I had not yet

Mr. Hibbert.

verified. You will remember that in the verbal epitome of my paper that I gave you, I did say at the end of it that after I had done with the cells and had resumed my ordinary winter's work they were placed on a cab in London, and the cab was given specially chosen difficult work in order that the cells if possible might be knocked to pieces. Practically, the instructions were, if it be possible to break them down by running about, to do so. Five out of the 60 have been somewhat injured as far as capacity is concerned. They are decidedly lower than they were at the time when I turned them over. From that time to this I have had nothing to do with them, except in so far as one or two of them have been sent to me to see what was the matter. This afternoon, along with the verification of those curves of the new form of cell which I have handed to you, I accompanied that experiment with a discharge of a cell that had been sent to me as having diminished in capacity. It was one of those that originally had a capacity of 158 ampere-hours, and when it came back to me its capacity had fallen to something like 75 or 80. This afternoon, after a tolerably simple process of regeneration, I brought it back to 122, and I anticipate—it is only anticipation, and not knowledge—it could be brought back much nearer to the 158 ampere-hours which it had at the beginning. The process to which I refer is tolerably simple. It consists very largely in giving it not only a big discharge but a reversed current for a fair length of time. The reason why you do not get back to the original state, in my opinion, is due to the fact that after such treatment not one or two or three charges but more—as we have already heard from Dr. Fleming—are required to bring even an ordinary cell, which has not been so seriously injured, back to its normal standpoint. If you conjoin with this fact another anticipation of mine—that by a very simple procedure I think I can prevent the mischief which brought down the capacity—I do not know, but I anticipate that I can, and I am going to try—if you conjoin the fact that I have already restored 40 per cent. of its capacity to it with the fact that I may be able to prevent the reduction in capacity in the future, it seems to me that the fact that five out of the 60 cells show a diminution (some out of the five to a large extent, and others to a smaller extent), under circumstances which led me originally to protest against their being used in that way, ought not to diminish, but might possibly increase, our confidence in the results which I described to you on a previous occasion.

The following paper was then discussed :—

ON THE MAGNETIC DISPERSION IN INDUCTION MOTORS, AND ITS INFLUENCE ON THE DESIGN OF THESE MACHINES.*

By Dr. HANS BEHN-ESCHENBURG, of the Oerlikon Machine Works. †

I.

ON THE DISPERSION-COEFFICENT σ.

As is known, in the theory of induction motors, a dominant part is played by the coefficient of magnetic dispersion which may be defined by the expression—

$$\sigma = 1 - \frac{M_1 M_2}{L_1 L_2}; \quad \ldots \ldots \ldots \quad (1)$$

wherein M_1 and M_2 denote the coefficients of mutual induction, L_1 and L_2 the coefficients of self-induction of the corresponding winding elements of the inducing and induced systems. The coefficient σ is most simply obtained experimentally as the quotient of the magnetising current by the short-circuit current at equal terminal potentials. If we neglect the relatively small correcting terms which depend on the ohmic resistance and the no-load losses, the dispersion-coefficient may be approximately stated by the expression—

$$\sigma = \frac{J_o}{J_k}; \quad \ldots \ldots \ldots \ldots \quad (2)$$

where J_o denotes the no-load current, and J_k the short-circuit current, reduced to equal terminal potentials.

Here at the outset, for fixing the limits of accuracy which in this investigation will be assumed as convenient, let it be laid down that the values of σ experimentally obtained for motors of equal size and precisely similar winding, differ amongst themselves frequently from 10 to 20 per cent., probably because the dimensions of the air-gap, of the slots, of the winding pitches, etc., which determine the magnitude of σ, cannot, in different examples of the same type, actually be turned out alike with mathematical precision. The experimental values deduced in the following investigations to determine the coefficient σ are mean values selected with great precaution from a large series of machines of similar type, or from observations made on some individual motor in which the separate dimensions could be varied. The distinct

* The researches described in this communication were imparted in April, 1903 to Professor Silvanus P. Thompson, on whose suggestion they were communicated in their present form to the Institution of Electrical Engineers in the summer, and have since been translated into English.

† Read at Meeting of January 14, 1904.

importance of the coefficient σ lies, as is known, in the limitation by it of the maximum power-factor, and of the capacity for overload of the motor. As is known, we have the approximate relation—

$$\cos \phi_{max.} = 1 - 2\sigma;$$

and the maximum torque, relatively to the torque which exists at the maximum power-factor, is:—

$$y = \frac{1}{2\sqrt{\sigma}};$$

Let it be assumed that σ lies between the limits 0·1 and 0·02, and that the accuracy of the values of σ for a motor of known dimensions does not exceed 10 per cent., then the accuracy in the predetermination of the maximum power-factor will attain about 1 per cent., and that of the capacity for overload about 6 per cent. But these are degrees of accuracy which quite equal the accuracy of the experimental determination of these qualities attainable in practice.

In accordance with these limits of accuracy, it seems convenient to confine an investigation into the dispersion-coefficient to a qualitative separation of the most important factors which in any general consideration are the determining ones, and to an experimental fixing of the order of magnitude of these factors. The coefficient σ appears to be made up of a series of single terms and factors, to which in the various theories different degrees of importance are attributed. So long as these individual quantities cannot be systematically separated experimentally one from the other, one may easily find a concordance between the total values of σ as ascertained by experiment and as calculated by theory, even though the theoretical composition of the total value out of the individual considerations were false.

II.

THEORY.

In order not to complicate inconveniently the theoretical part of this investigation, consideration will from the outset be confined to a three-phase motor the primary and secondary systems of which possess equal numbers of windings, which are arranged in the same manner in an approximately equal number of similar slots, so that the dispersion-ratios in the two systems may be approximately equal, or at least capable of being expressed by a mean value. In due course, in the experimental part, it will be considered what is the influence which any departure from this hypothetical uniform arrangement of windings will exert. Moreover this assumption, while making for simplicity, is useful in demonstrating relations which depend upon σ, and it will be shown that within the above-stated limits of accuracy it is of general validity.

Further, in what follows, we make the assumption generally that the so-called magnetic resistance in the iron parts of the motor is

small in comparison with the magnetic resistance of the air-gap. This condition may obviously always be fulfilled if we confine ourselves to such degrees of saturation that the magnetising current is proportional to the terminal voltage.

In formula (1), giving the definition of σ, it is primarily to be noted that σ must practically be a quantity smaller than 0·1; and that having regard to the degrees of accuracy required in practice, quantities smaller than 0·1 are negligible relatively to unity. For a motor with stator and rotor windings that are alike, we may substitute :—

$$M_1 = M_2 = M;$$
$$L_1 = L_2 = L;$$

whence—

$$\sigma = \frac{L^2 - M^2}{L^2} = 2 \times \frac{L - M}{L} \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

In what follows we will apply the coefficients L and M to the winding of one group of coils, constituting one phase in one pole-pitch of the motor. Let w be the number of turns of this group of coils, and let the group consist of $\frac{N}{3}$ single coils, which are disposed in $2\frac{N}{3}$ slots. For the three-phase motor, N is therefore the number of slots per pole-pitch. Then $\frac{L}{w}$ denotes the magnetic flux which intersects the windings w when these same windings are traversed by a current of strength $= 1$. Also $\frac{M}{w}$ is the magnetic flux which intersects the windings of one system when the windings of the other system are traversed by a current of strength $= 1$.

§ 1. The Winding-Coefficient.

In every motor there necessarily exists a difference between the self-induction of the winding of one system and the mutual-induction between corresponding portions of the windings of the primary and secondary systems, even if there were no so-called magnetic leakage to influence the relation.

To simplify the exposition, let us consider a motor in which both systems possess a precisely similar number of slots, and in which the iron teeth lying between the slots are of precisely similar form. Let both systems be wound in the usual manner; in fact, let one system contain a primary winding which is arranged in the manner of the three-phase motor in one-third of the slots within the pitch of one pole, while the induced system consists of a number of conductors regularly distributed in all the slots. It will be assumed that no leakage is present in the two systems. Then let us distinguish two extreme positions in which the two systems may be placed opposite to one another—*i.* the teeth of one system stand exactly opposite the teeth of the second system; *ii.* the teeth of the one system stand exactly opposite the slots

or holes of the second system. In both positions let the same number of magnetic lines be generated by the primary winding, and pass over from the teeth of the first system into the teeth of the second system. It is self-evident that in the former position the mutual-induction will be exactly equal to the self-induction, since the secondary conductors are surrounded by exactly as many magnetic lines as are the primary. In the latter position, on the contrary, a portion of the magnetic lines will enclose a smaller number of secondary conductors than they do in the former position.

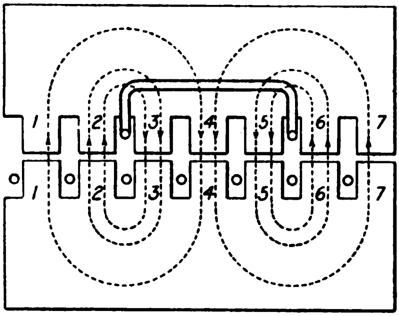

FIG. I.

The total amount of the mutual-induction may be measured in a simple way as the sum of a set of products, each product being the amount of a branch of the magnetic flux proceeding out of a primary tooth multiplied by the number of secondary conductors which this branch of the flux surrounds until it again returns into the primary system. The difference between the amounts so reckoned of the mutual-induction in the two extreme positions gives the loss of the mutual-induction which occurs in the second position. This loss is equal to the difference between the self-induction and the mutual-induction in this second position. But now, since during the operation of the motor, in consequence of the slip, the teeth of the two systems glide past one another in their relative positions, it follows that half the difference of the mutual-inductions in the two extreme positions will indicate the mean value of this difference while running. If one exchanges the respective *rôles* of the primary and secondary systems, the estimate so made of this difference will apply equally to the stator system as to the rotor system of the motor. Strictly speaking, in this regard the windings of all the slots in their actual and complete relations ought to be taken into consideration. All the phases of the winding of the one system act successively and together upon all the phases of the winding of the second system. In consequence there occur in general at definite places in each system the known distortions and inequalities of the magnetic field, and these are bound up with the practical limitation of the number of current-phases to two, three, four,

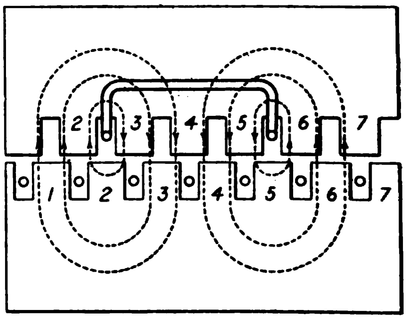

FIG. IA.

or six phases. In the case of three-phase windings this inequality may amount to 15 per cent. But this complete investigation would entail difficulties out of proportion to its usefulness, having regard to the desired limits of accuracy. The principle of the phenomenon, and also the magnitude of the determining relations, admits of being expressed to a sufficiently close approximation in a simple investigation which takes into account one phase only of the primary winding of a three-phase motor.

Let us assume, as the first and simplest case, a motor possessing in its primary and secondary systems three slots and three teeth per pole-pitch. The primary winding in one phase may be represented by a single turn, which lies in the slots 2 and 5 (see Fig. 1) of the primary system. The secondary system has one conductor, L, in each slot. The slots and teeth of each system are numbered progressively from left to right. Doubtless the schematic representation of the figures

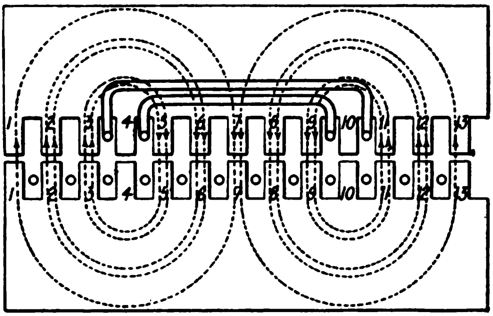

FIG. 2.

will be intelligible without further explanation. Let the arrow-heads indicate the course of the magnetic lines, and let each arrow denote a portion of the magnetic flux amounting to the value f.

From the figure the amount of the mutual-induction may now be read off in the following manner, namely, that each separate partial re-entrant magnetic flux of amount f will be multiplied by the number of secondary conductors L which it embraces. From the middle tooth 4 there emerge to left and right two magnetic fluxes each of value f, each of which surrounds three conductors. Therefore the tooth 4 contributes toward the mutual induction an amount equal to $2 \times f \times 3 \times L$. From each of the teeth 3 and 5 there emerge two fluxes f, each of which surrounds one conductor, namely, conductors 2 and 5 respectively. These fluxes, therefore, contribute the amount $2 \times 2 \times f \times 1 \times L$. The total mutual-induction of this system in this position may therefore be stated as of the value :—

$$2f \times 3\,L + 2 \times 2f \times 1\,L = 10\,(f \times L).$$

In Fig. 1A the same system is depicted in the second position, in which the teeth of one system stand opposite the slots of the other.

Let the same total magnetic flux as before pass over from each tooth of the primary system into the secondary system; but it must now divide itself between two teeth of the secondary system.

But a mere superficial observation makes it evident that a part of the flux now no longer encloses any secondary conductors, and that, on the other hand, the secondary conductor No. 3 is not surrounded by any flux.

Let us count up, as for Fig. 1, the amount of the induction; then we find for the fluxes which emerge from the middle tooth 4 the induction values $2f \times 2\,L$; for the fluxes of teeth 3 and 5 the values $2f \times 2\,L + 2f \times 0\,L = 2 \times 2f \times L$. The sum of these is now $8f \times L$; that is to say, only 80 per cent. of the mutual-induction as it was in the first position. In other words, we therefore lose in this position 20 per cent. of the total flux for the mutual-induction.

If we carry out the similar investigation for a primary and a secondary system with six slots per pole-pitch, in which the winding of the primary system consists of two windings lying in two (pairs of) slots, we then obtain, according to Figs. 2 and 2A, in the first position a total of $36f \times L$, in the second position $33f \times L$. In the second position we therefore lose about 10 per cent. of the mutual-induction, or in the mean between the two positions about 5 per cent.

In a similar way we get for two systems with nine slots per pole-pitch, and a primary winding of three windings distributed in three (pairs of) slots, in the first position a total of mutual-induction of $119f \times L$; in the second position, $114f \times L$. (In this case there is assumed for calculation a flux of $3\,f$ in each tooth of the primary system that is entirely surrounded by three primary windings.)

For systems with 15 slots per pole-pitch and 5 primary windings one gets, in the first position $545\,f \times L$; in the second position $538f \times L$. (In this case there is assumed a flux of $3f$ in a primary tooth which is surrounded by all five windings.)

If now, in place of the two systems having equal numbers of slots, we examine the case of two systems with unequal numbers of slots, then the distribution of the magnetic fluxes through the individual teeth takes a rather more complicated form in the different positions. But the character of the phenomenon is quite like that of the cases above considered. In general there can be found two positions in which the value of the mutual-induction is respectively a maximum and a minimum. The maximum value agrees approximately with the value of the induction in the first position of the system with equal numbers of slots. But in this the values are to be compared with the primary system for equal numbers of slots, and with the secondary system as to equal numbers of conductors. For example, if a secondary system with 9 conductors in 9 slots is to be compared with a system of 15 conductors in 15 slots, then the value of the induction in the first case must be raised in the proportion 15 : 9, since in each slot 15/9 of a conductor will be assumed.

Also in the cases of systems with different numbers of slots the action on one another of all the phases of the primary current strictly stated, must be taken into consideration. Then the influence of the

inequality of the field will have a predominant effect. Further, the distribution of the winding, and the winding-pitch in the two systems must be accurately set out for each particular case. These influences, however, involve very detailed expressions, and yet they exercise on the character of the phenomenon and on the magnitude of the relations involved so little change, that they may be passed over in the scope of this enquiry, the difficulty of which lies rather in its experimental part.

As an example we consider, as in Figs. 3 and 3A, the mutual-induction of two systems of which the primary system has six slots per pole-pitch, with two windings as in Fig. 2, and the secondary system 9 slots per pole-pitch with 9 conductors.

In the first position, Fig. 3, the amount of the mutual-induction is $54 f \times L$; in the second position, $52 f \times L$. If the secondary number of conductors 9 is for comparison with Fig. 2 reduced in the proportion 6 : 9, then in the first position we have the value $54 \times \frac{6}{9} \times f \times L = 36 f \times L$, exactly as in Fig. 2. In the second position, Fig. 3A, the

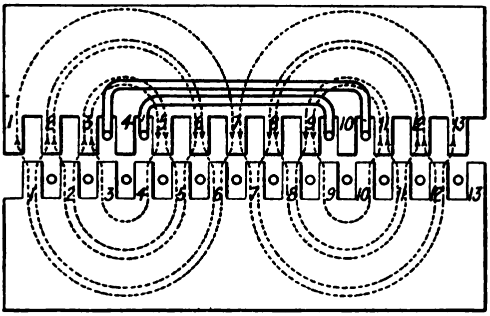

FIG. 2A.

amount is $34{\cdot}6\ f \times L$, while in Fig. 2 the amount $33\ f \times L$ was obtained.

A similar calculation was made for a primary system with 9 slots and 3 windings, and a secondary system with 15 slots and 15 conductors. Here there was found in one position the value $199 f \times L$, in a second position the value $196 f \times L$. For comparison with the values which were given above for two systems with equal numbers of slots, 9 per pole-pitch, these values must be reduced to equal numbers of conductors. Thus one obtains for the systems with 9 and 15 slots in the first position the value $119{\cdot}5 f \times L$; in the second position, $117{\cdot}5 f \times L$; for the system with 9 slots in both primary and secondary we have earlier found in the first position $119\ f \times L$, in the second position $114 f \times L$.

These considerations have been set out with this completeness, because they afford an insight into an essential element of the so-called dispersion-coefficient σ which does not arise out of ordinary magnetic leakage, but which must also occur in an ideally leakage-free motor; and in general the magnitude of this element will be greater than the so-called peripheral leakage.

In order to obtain a view into the order of magnitude of this effect, which we shall denote as the effect of the distribution of the winding, or effect of the *winding-coefficient*, let us assemble in a Table the

Number of Slots.		Induction.		Half-Difference / Maximum Value = Winding-coefficient.
Primary.	Secondary.	Maximum.	Minimum.	
3	3	10	8	10 per cent.
6	6	36	33	4·2 „
6	9	36	34·6	2·3 „
9	9	119	114	2·1
9	15	199	196	0·75 „
15	15	545	538	0·6 „

numerical values above obtained. As a measure of the influence of the winding-coefficient we may regard the quotient of the difference of the maximum and minimum values of the induction divided by the maximum value. In order to be able to assign beforehand to these coefficients a mean value for all possible different positions of the two systems, we insert in the quotient the *half* of the difference between the maximum and minimum values.

In the same way we have to consider the combination of a limited number of phases in the stator and rotor windings. There are slight fluctuations, on the one hand of the self-induction of the combined stator windings, and of the combined rotor windings, and on the other hand of the mutual-induction between the stator and rotor windings, fluctuations which depend on the different positions of the rotor, and on the variations from instant to instant of the primary current. In a motor with three-phase stator windings and three-phase rotor windings, we must distinguish two particular positions of the rotor and two particular moments in the periodical changes of the current. In the first position the three phases of the rotor winding correspond exactly to the three stator phases; in the second position the rotor phases are displaced $\frac{1}{6}$ of the pole-switch. Further, the first moment in the changes of the current is taken when the current of one phase is at its maximum; the second moment when it is at its zero value. If we compare the mean value of the self-induction of the three stator phases, in these four cases, with the mean value of the mutual-induction between the three stator phases and the three rotor phases, we observe a small difference which diminishes rapidly with an increase in the number of slots; for example, for six slots per pole this difference may amount to 1·2 per cent., for twelve slots to 0·4 per cent. We have here further to consider the influence of the wave-form of the primary

currents on these effects, which we put together under the designation of "winding-coefficient."

However complicated the relation between the winding-coefficient

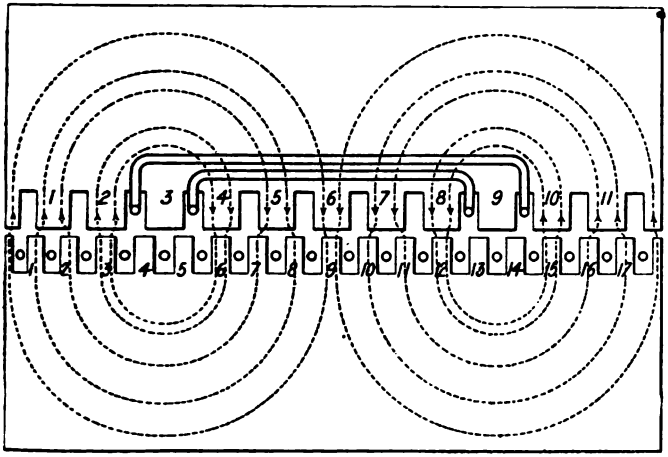

FIG. 3.

and the primary and secondary numbers of the slots in the parts may be, yet it must always be smaller the larger the number of the slots, of the primary on the one hand or of the secondary on the other. Let us denote by N the mean value between the primary and secondary numbers of slots per pole-pitch, then broadly, as we are here dealing

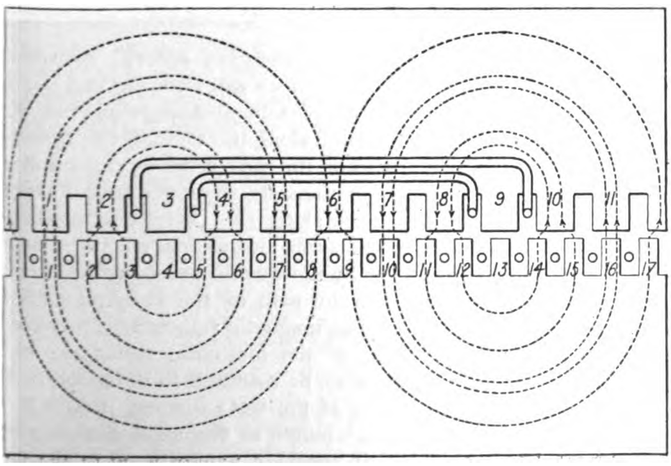

FIG. 3A.

with the subject, this coefficient which will denote by σ_1, may be set out by the expression :—

$$\sigma_1 = 1{\cdot}3 \frac{K_1}{N^2}; \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

where K_1 has the meaning of a function of N to be determined experimentally from case to case, but which generally differs but slightly from the constant-value of unity, and in general also expresses all those influences which may arise from the various distributions of the winding in different parts of the phase, and from the winding pitches. In the coefficient K_1 are also contained the effects of the form of slots or teeth upon these phenomena, and on the influence of the inequalities of magnetic reluctance in different positions.

In the cases hitherto considered, we have indeed discriminated between primary and secondary systems, but it is immediately evident that in the motor each of the two winding systems, stator or rotor, has for the carrying out of this calculation to be regarded as at one time acting as primary, and at one time as secondary.

The value of σ_1 according to formula (4) may now at once be inserted in formula (3), since, as above explained, we may put the maximum value of the induction as proportional to the coefficient of self-induction L, and the mean value as proportional to the coefficient of mutual-induction M. Therefore we have :—

$$\frac{L - M}{L} = \sigma_1 + \Delta;$$

where Δ denotes a residual term which arises from other relations than those described under the name of winding-coefficients. We now discover as a further cause for the difference L—M, the occurrence of the so-called magnetic stray fields or magnetic dispersion, as will be described in the following sections.

§ 2. Peripheral Dispersion (*Mantelstreuung*).

In every motor there come into operation several considerable magnetic dispersions or leakages, which we will separate into two stray fluxes. One of these, the so-called peripheral dispersion, runs along the face of the bore of the stator, and along the face of the cylindrical periphery of the rotor, since between the tops of the iron teeth of each single system, over the openings of the slots, there occurs a leakage of magnetic lines. These stray fluxes along the peripheral surface will bear to the mean total flux F the same proportion as the magnetic reluctance of the path followed by the flux F bears to the magnetic reluctance which is interposed in the path of the stray magnetic flux between the tops of the teeth. The magnetic reluctances between the tops of two neighbouring teeth, or the magnetic reluctance of the opening of a slot may, for open slots, be assumed to be about proportional to the width X of opening of the slot; further, it is of course inversely proportional to the tooth-length in the axial direction, or to the iron-length b of the core, and inversely proportional to the thickness of the layer in which the passage occurs. This thickness may be

set down tentatively for the usual forms of slots as 0·1 cm. In order to take into account the influence of the special forms of slots in particular cases, we will further introduce a coefficient K_2, which will require to be experimentally determined. Then we may set :—

$$\rho = \frac{X}{0{\cdot}1 \times b \times K_2}.$$

For closed slots, in place of the air-slit in the peripheral surface there is a very thin bridge of iron. The thickness of this iron bridge will amount to about 0·1 mm. at the thinnest place. These iron bridges ought, under normal running, to become completely saturated by the stray flux, so that for their resistance we make reckon them tentatively to have a permeability as low as $\mu = 100$. If now the length of the iron bridge at its thinnest place amounts to, say, X cm., then the magnetic resistance for the closed slot may be set at :—

$$\rho' = \frac{X}{b \,.\, K_2}.$$

The stray flux along the peripheral surface of the iron cylinder forms a magnetic circuit surrounding the primary coils which will be distributed in the slots over a third of the pole-pitch. The chief resistance in this circuit is constituted by the paths of passage at the openings of all those slots which at the peripheral surface include one primary coil. If, as before, N denotes the number of slots in one pole-pitch, then one primary coil is included or bridged over by $\frac{N}{3}$ slot-openings. The resistance of the magnetic circuit of the stray flux f is therefore about equal to $\frac{N}{3} \times \rho$. The resistance in the path of the main flux F which passes out of the primary system into the secondary is, approximately :—

$$R = \frac{3\,\delta}{2\,\tau \times b};$$

where δ is the air-gap length from iron to iron, b the axial length of the iron core, τ the length * of the pole-pitch at the face.

We may denote by the coefficient σ_2 the quotient of the stray flux f by the main flux F, and obtain approximately :—

$$\sigma_2 = \frac{f}{F} = \frac{R}{\frac{N}{3} \times \rho} = \frac{K_2\,\delta}{2\,N \times \tau \times X}, \text{ for open slots ;} \quad . \quad . \quad . \quad (5)$$

and—

$$\sigma'_2 = \frac{5\,K_2\,\delta}{N \times \tau \times X}, \text{ for closed slots.} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5\text{A})$$

§ 3. Flank Dispersion (*Stirnstreuung*).

A second kind of magnetic dispersion which also occurs in every

* For motors in which the peripheral surface is interrupted by openings of slots, the length τ must be reduced by about the total width of all the openings of slots within one pole-pitch, corresponding to the increase of no-load current produced by these openings.

motor consists of the magnetic flux which exists outside the iron core. Those parts of the winding which constitute the end connexions between conductors in the slots, and which project as curved winding-bunches or bends at the flanks of the stator and rotor cylinders, give rise to a magnetic flux outside the iron core-bodies. This flux surrounds these curved connexions in such a manner generally that only a small fraction of the flux created by the bends of the one system intersects the bends of the other system. These bends, or end connexions at the flanks of the motor, are in the motors of ordinary construction more or less closely or completely surrounded by the solid iron parts which form the housing, the casing, and the clamping-plates for the laminated core-bodies. Yet it is possible so to choose the distance between the winding and these iron structures that only a small part of the stray flux created by these parts of the coils (and which we shall call flank-dispersion) passes into iron.

In the main this stray flux is equal to the magnetic flux which would

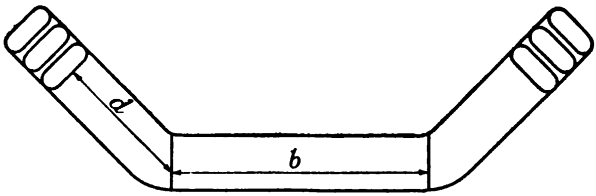

FIG. 4.

be created by an independent group of coils of a form similar to the two projecting bends at the two flanks, if put together as a coil. What is necessary is therefore to determine the self-induction coefficients of similarly constructed coils, and the coefficients of mutual induction between such coils if placed in such positions relatively to one another as would about correspond to the respective positions of the projecting bends in the stator and the rotor.

There was undertaken a series of self-explanatory measurements on variously shaped coils of this sort, away from any iron cores, in order to obtain practically for the various forms reasonable estimates of the influence of the lengths of the windings, the distribution of the windings in separate coils, and the mutual-induction between the coils. In this investigation one is chiefly concerned with two shapes of coil, viz.:—

(*i*) With coils the end bends of which are straight out, or in approximately the same (cylindrical) surface as that in which lie those portions of the coils that are placed in the slots;

(*ii*) With coils the end bends of which are bent up or down out of this surface.

Fig. 4 depicts a group of 3 straight-out coils nested against one another; Fig. 5 a group of 3 coils having the bent ends turned up.

The details of the research of the different forms of coil may here

be passed over. The results can be assembled in the following practical rules :—

The coefficient of self-induction of a single coil which consists of

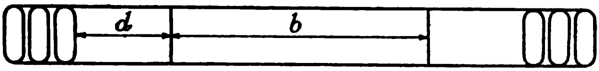

FIG. 5.

W turns having a mean length of one turn l, is approximately for all forms existing in practice :—

$$\lambda_1 = 6 W^2 \times l.$$

The coefficient of self-induction of a group of coils, which are laid within one another at small distances apart as are the coils in motors, having a total number of turns W and a mean length of turn l, amounts approximately to

$$\lambda_2 = c \times 6 W^2 \times l;$$

where c varies between 0·7 and 0·55 for groups of 2 to 5 coils, or on the average

$$\lambda_2 = 3·6 W^2 \times l.$$

If into the neighbourhood of the coils iron bodies are brought which may represent the nearest iron parts in the neighbourhood of the bent ends at the flanks of the motor, then the coefficient of self-induction will be increased about 20 per cent. The mutual-induction between the end bends of the stator and rotor may diminish the value of the self-induction by 20 to 50 per cent. according to the arrangement of the bends.

The coefficient of mutual-induction of straight-out coils, which are held at the usual distance from one another, amounts to about 50 per cent. of the coefficient of self-induction; the coefficient of mutual-induction between a straight-out and a bent-up coil, or between two coils bent-up in opposite directions, amounts to about 20 per cent. of the coefficient of self-induction.

As a mean value for the coefficient of self-induction of the end-bends, which cause the flank-dispersion, after taking account of the influence of the iron masses and of the mutual induction, we may write :—

$$\lambda = K_3 \times 3·5 \times W^2 \times l;$$

where the coefficient K_3 relates to the influence of the winding arrangements and of the iron structures, so far as these depart in special cases from a mean value. For l, the mean length of one winding of the end bends lying outside the slot, we deduce from the dimensions of the motor an approximately generally valid relation, which may again in special cases require to be reduced to a mean value by the insertion of a coefficient.

The length of the bend of one coil comprised at the two flanks is

equal to double the length of the pole-pitch τ, increased by adding four times the distance which the end-bends project beyond the core-body. But the length of this projection is itself approximately proportional to the pole-pitch, since the coils must stand out so much the further the more the intervening coils over which the end winding has to span. So we put :—

$$l = 3\,\tau \times K_4,$$

and so get approximately—

$$\lambda = K_5 \times 10 \times W^2 \times \tau \,; \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

in which the constants K_3 and K_4 are comprised in the constant K_5.

In order to ascertain how much this species of self-induction contributes to the dispersion-coefficient σ, this coefficient of self-induction λ must be divided by the coefficient of self-induction, L, of the whole winding.

Now, according to the known formulæ, we have approximately—

$$L = \frac{4\pi \times W^2 \times b \times \frac{2}{\pi}\tau}{2\,\delta} = \frac{4\,W^2 \times b \times \tau}{\delta},$$

and the flank-dispersion therefore has a dispersion-coefficient σ_3 defined * by—

$$\sigma_3 = \frac{\lambda}{L} = \frac{2{\cdot}5 \times K_5 \times \delta}{b} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

Since K_5 signifies, just as K_3 did, a constant needing to be determined experimentally, we shall in that which follows write simply K_3 in place of K_5.

To the losses of magnetic flux indicated under the preceding sections, § 1, § 2, and § 3, there may in special cases be adjoined other losses not here specifically considered. For the following experimental investigation we confine ourselves to these three sources of loss, and collect together for the estimation of σ the results now obtained.

By formula (3)—

$$\sigma = 2\,\frac{L - M}{L}.$$

By formula (4)—

$$\frac{L - M}{L} = \frac{1{\cdot}3 \times K_1}{N^2} + \Delta.$$

Now Δ consists, on the one hand, of the coefficient σ_2 indicated in formula (5)—

$$\sigma_2 = \frac{K_2 \times \delta}{2 \times X \times N \times \tau};$$

* As remarked on p. 249 above, it is necessary, in the case of motors with slots that are open at the peripheral surface, to reduce the value of τ in the formula for L by an amount about equal to the total width of all the slot-openings within one pole-pitch, corresponding to the increase of no-load current consequent upon the presence of these openings. Or, in formula (7) one must increase the value of δ, the effective air-gap, in corresponding inverse proportion.

and on the other hand, of the coefficient σ_3 of formula (7)—

$$\sigma_3 = \frac{2\cdot5 \times K_3 \times \delta}{b}.$$

Therefore we obtain—

$$\sigma = K_1 \frac{2\cdot6}{N^2} + K_2 \frac{\delta}{X \times N \times \tau} + K_3 \frac{5 \times \delta}{b}. \quad . \quad . \quad . \quad . \quad (8)$$

The individual constituents of σ, we may for simplicity of exposition denote thus—

$2\ \sigma_1 = K_1 \frac{2\cdot6}{N^2}$ is the Winding-coefficient (see equation 4);

$2\ \sigma_2 = K_2 \frac{\delta}{X \times N \times \tau}$ is the Peripheral dispersion;

$2\ \sigma_3 = K_3 \frac{5 \times \delta}{b}$ is the Flank dispersion;

and

$$\sigma = 2\ \sigma_1 + 2\ \sigma_2 + 2\ \sigma_3. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

It is now easy to discern how these three coefficients may be separated in the experimental way. The coefficient σ_1 is dependent only on the number of slots of one phase of the pole-pitch; the coefficient σ_2 alone depends on τ and X; the coefficient σ_3 alone depends on b; while σ_1 alone is independent of δ.

We have, therefore, to compare the experimentally-found values of σ for different types of motors, in which one of these dimensions varies while the remaining dimensions are kept constant.

Now the Oerlikon Machine Works has at its disposal a large number of motors in which this variation of single dimensions has been carried out systematically; as, for example, having slots alike but with different lengths of core-body, or having slots alike, and core-body length alike, but with different numbers of poles, and so forth. Moreover, the air-gap and the width of slot-openings were systematically altered in a number of similar individual motors. Further, researches were at hand upon different numbers and forms of slots; and it was therefore possible to make, from the collection of test-schedules, which in recent years had been recorded about three-phase motors, a selection such as would afford an insight into the values of the various coefficients, and a determination of the separate factors. It is withal to be remarked that the material in this investigation is not exclusively comprised of values ascertained by observation taken with the greatest accuracy, and the direct object of comparisons of this sort. It is rather concerned in general with values which, in accordance with the practice of a factory laboratory, are ascertained in the first instance for the purpose of a rapid and convenient estimation and control of the efficiency of the machine to be delivered. Any way, a suitable selection from the very large number of machine tests may, in respect of practical usefulness, and the availability of the mean values of existing materials, partially replace the scientific preference of systematic researches.

We employ for brevity the following symbols :—

P = number of poles.
N_1 = number of slots of the stator.
N_2 = number of slots of the rotor.
D = diameter of the bore, in cm.
δ = air-gap, in cm.
b = axial length of core-body, in cm.
τ = pole-pitch, in cm.
X = width of opening of the slots.

The values of σ inserted are the quotients of the no-load current J_o and the short-circuit current J_k taken direct from the readings, without regard to the ohmic resistance of the windings and the no-load losses. For J_o those values only were considered as reliable which showed a regular proportion between current and voltage, so that J_o should be really dependent only on the magnetic resistance of the air-gap. Therefore we have :—

$$\sigma = \frac{J_o}{E_o} \times \frac{E_k}{J_k};$$

where E_o denotes the voltage at which the no-load current J_o was observed, and E_k the voltage at which the short-circuit current J_k was observed.*

The principle of this exposition of the dispersion-coefficient σ is so framed that (for the purpose of the research) σ can be resolved into a part σ_1 which is dependent only on the square of the number of slots, and into a second part which is proportional to the air-gap. This second part is again resolved into a part σ_2, which is dependent on the magnetic resistance of the slot-opening, and a part σ_3, which is dependent on the length of the core-body. The problem then is to investigate whether such a resolution of the total dispersion-coefficient into three separate functions can be confirmed by the observations, and whether therewith there can be attained an estimation of the total dispersion-coefficient sufficiently permissible and complete for the needs of practical design.

III.

EXPERIMENTAL PART.

§ 1. Flank Dispersion.

The member σ_3 in formula (7) obviously may be eliminated most easily, since σ_3 is the only quantity which depends on the length of iron in the core-body. If, therefore, we compare the values of σ for two motors in which the number of poles, the number of slots, shape of slots, and the air-gap are maintained the same, while the iron-breadth

* As is known, σ may also be determined on the stationary motor with open secondary circuits, from the transformation-ratios of the primary and secondary systems. But for small values of σ this method of determination is obviously very inexact and inconvenient, so that it is not employed in the following pages.

in one motor amounts to b and in the other to b', then the coefficients σ_1 and σ_2 for both motors will be the same, whereas the total values σ and σ' of the dispersion-coefficient will differ from one another by the difference of the coefficients σ_3 in the two cases. Whence we get—

$$\sigma - \sigma' = 5\delta \cdot K_3 \cdot \left\{ \frac{1}{b} - \frac{1}{b'} \right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

Now the Oerlikon Machine Works builds various series of normal types of motors amongst which are found motors with diameters, numbers of poles, and shape of slots that are equal amongst themselves, and which differ only in their iron-breadth. We will apply the above calculation to some of these types of motors, and first for motors with the usual coil-winding, in which the hand-shaped coils projecting at the flanks of the core-body are bent down over one another against the end plates.

(1) *Motor Type* 358 : *Insulated Coil-winding in Stator and Rotor.*

With 4 poles, $\sigma = 0{\cdot}06$; with 6 poles, $\sigma = 0{\cdot}09$.
$D = 29$; $\delta = 0{\cdot}065$.
$N_1 = 72$; $N_2 = 96$.
$b = 10$.

Motor Type 359 : $\begin{cases} \text{With 4 poles, } \sigma' = 0{\cdot}045. \\ \text{With 6 poles, } \sigma' = 0{\cdot}075. \end{cases}$

$D' = 29$; $\delta' = 0{\cdot}065$.
$N'_1 = 72$: $N'_2 = 96$.
$b' = 14{\cdot}5$.

The difference of the values of σ in the two motor types gives for 4 poles :—

$$\sigma - \sigma' = 0{\cdot}015 \text{ ; for 6 poles, } \sigma - \sigma' = 0{\cdot}015 \text{ ; and } b' = 1{\cdot}45 \times b.$$

According to formula (8) one would have $\sigma - \sigma' = K_3 \times 0{\cdot}01$. By comparison with the above we should obtain for these types of motors—

$$K_3 = 1{\cdot}5.$$

The same types of motor, but provided with a non-insulated short-circuited winding in the rotor, gave :—

Type 358 (4-pole) $\sigma = 0{\cdot}05$.
Type 359 (4-pole) $\sigma' = 0{\cdot}04$.
$\sigma - \sigma' = 0{\cdot}01$; $K_3 = 1$.

(2) *Motor Type* 838 : $\begin{cases} \text{With 6 poles, } \sigma = 0{\cdot}050. \\ \text{With 8 poles, } \sigma = 0{\cdot}063. \end{cases}$

$D = 49$; $\delta = 0{\cdot}08$.
$N_1 = 72$; $N_2 = 120$.
$b = 19$.

Motor Type 840: $\begin{cases} \text{With 6 poles, } \sigma' = 0{\cdot}042. \\ \text{With 8 poles, } \sigma' = 0{\cdot}056. \end{cases}$

$D' = 49$; $\delta' = 0{\cdot}08$.
$N'_1 = 72$; $N'_2 = 120$.
$b' = 28$.

With 6 poles, $\sigma - \sigma' = 0{\cdot}008$.
With 4 poles, $\sigma - \sigma' = 0{\cdot}007$.

By formula (8)—

$$\sigma - \sigma' = 5 \times 0{\cdot}080\ K_3 \left(\frac{1}{19} - \frac{1}{28}\right) = K_3 \times 0{\cdot}065.$$

By comparison of observation and calculation we have :—

$K_3 = 1{\cdot}25$ for 6-pole winding;
$K_3 = 1{\cdot}1$ for 4-pole winding.

Motor Type 8052 :—With 12 poles, $\sigma = 0{\cdot}067$.

$D = 90$; $\delta = 0{\cdot}1$.
$N_1 = 144$; $N_2 = 180$.
$b = 17$.

Motor Type 3068 :—With 12 poles, $\sigma' = 0{\cdot}046$.

$D' = 90$; $\delta' = 0{\cdot}1$.
$N'_1 = 144$; $N'_2 = 180$.
$b' = 40$.

Therefore from observation, $\sigma - \sigma' = 0{\cdot}067 - 0{\cdot}046 = 0{\cdot}021$: by calculation, $\sigma - \sigma' = K_3 \times 5 \times 0{\cdot}1 \left\{\frac{1}{17} - \frac{1}{40}\right\} = K_3 \times 0{\cdot}017$; whence we get :—

$$K_3 = 1{\cdot}24.$$

From these examples, for motors with similar arrangements of windings, that is with coils bent down over the flank surfaces, the coefficient K_3 may with tolerable accuracy be set down at the value $1{\cdot}25$.

We will, however, add an example which shows the influence of the arrangement of the windings at the flanks.

The dispersion-coefficients were measured of a motor the stator winding of which consisted of coils which were laid over one another in three planes, and having at one time a rotor which was also wound with insulated coils in three separate phases, and at another time a rotor the winding of which was carried out in the well-known squirrel-cage form. In both cases the number and shape of the slots in the rotor were alike, so that the two cases are distinguished only by the special arrangement of the conductors on the flanks of the rotor. It must be premised that the flank dispersion of the conducting pieces of the squirrel-cage rotor is very small in comparison with the dispersion of the curved bights of the coils fastened in the former case against the clamping rings.

The observations gave:—

Motor Type 363 :—With 8 poles.

$$\left.\begin{array}{l} D = 58; \quad \delta = 0{\cdot}09 \\ N_1 = 96; \; N_2 = 144 \\ b = 24. \end{array}\right\} \begin{array}{l} \text{Rotor with phase-winding, } \sigma = 0{\cdot}054. \\ \text{Rotor with squirrel-cage, } \quad \sigma = 0{\cdot}037. \end{array}$$

The greatest part of the difference $\sigma - \sigma' = 0{\cdot}017$, may now be attributed to the flank-dispersion of the rotor with coil-winding. One part of the difference will anyhow arise, winding-coefficients σ_1 and σ'_1 being different in the two cases. If the flank-dispersion of the rotor in the first case is taken as equal to the flank-dispersion of the stator, then accordingly we may set—

$$K_3 \times 5 \times 0{\cdot}9 \times \frac{1}{24} = 2 \times 3{\cdot}017;$$

whence

$$K_3 = 1{\cdot}8,$$

while we had found above as a mean value for the coil-winding $K_3 = 1{\cdot}25$. We will attribute to the winding-coefficient the half of the mean of these two values, and take, therefore, for this motor $K_3 = 1{\cdot}5$.

§ 2. Peripheral Dispersion.

After obtaining in the first section the value of the flank-dispersion, let us now investigate the value of the peripheral-dispersion, which was above defined by formula (5) as :—

$$2\,\sigma_2 = \frac{K_2\,\delta}{X \times N \times \tau}.$$

This dispersion is by definition characterised by its correlation with the magnetic resistance (reluctance) of the slot-apertures at the peripheral surfaces of stator and rotor. If the flank-dispersion is known with accuracy, then the peripheral-dispersion may also, in consequence of its dependence on the air-gap δ, be distinguished and separated from the amount due to the winding-coefficient σ_1. Examples will be adduced of both modes of determining σ_2.

A large number of normal types of motor of the Oerlikon Machine Works were built with closed slots in stator and rotor. The iron bridges which close the slots at the peripheral surfaces were machined down to a thickness of about 0·1 mm. and to a breadth of 1 to 2 mm. Obviously such a thin bridge of iron will already be fully saturated with a proportionately small magnetic flux. The magnetic resistance of such a bridge is variable according to the degree of saturation. The saturation augments with the number of ampere-turns which excite the stray flux over the peripheral surface. These ampere-turns are equal to the product of the number of turns in the slots of one phase into the strength of current in these turns. Motors with slots closed in this manner must be therefore so proportioned that the number of ampere-turns in their slots attains a sufficient value to saturate fully the iron bridges over the slots. For such motors the short-circuit current will, up to saturation, increase rapidly with the increase of the voltage applied during the short-circuit: and the value of σ will therefore fall

off rapidly with the increase of the short-circuit current. Obviously, we must here abandon those methods for the estimation of the characteristic values of the motor which are in the diagram based upon the assumption that σ is of constant value.

From the course of the curve of the short-circuit current as a function of the short-circuit voltage, it may be approximately read off at what point the saturation of the iron bridges sets in, since from that point onwards the curve runs on in a straight line. Let comparison be made between the value of σ, which corresponds to this point of the curve, and the value, for a simular motor, of σ which is obtained when the iron bridge over the slots is slit through with an air-gap. Always when the slots are opened by such air-slits the short-circuit currents are proportional to the short-circuit voltage, and σ becomes constant. In the formulæ (5) and (5A) the difference of the peripheral-dispersion

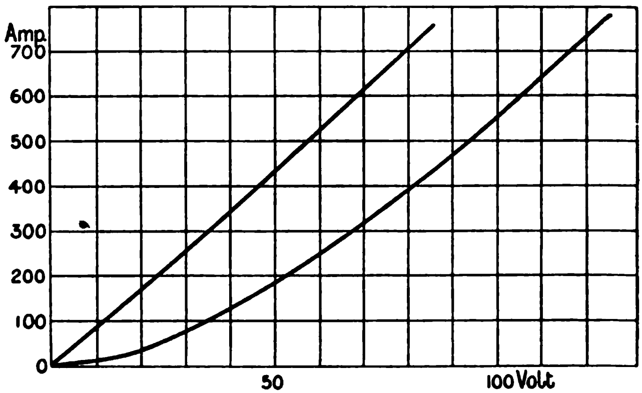

FIG. 6.

was tentatively given from theory as being for open slots ten times smaller than for closed slots with saturated iron bridges.

As a first example, let us take a motor of Type 367, which was first examined with closed slots with iron bridges about 0·1 mm. thick, and of a breadth of about 2 mm. Then in the same motor the slots in the stator and rotor were provided with slit openings of 3·5 mm. By these proportionately broad slits the effective length of the pole-arc τ is reduced, and with it the mean value of air-induction and of the magnetising current J_o* was raised in the proportion of 100 : 80. The normal current of the motor amounts to about 600 amperes at 190 volts. For this current the number of ampere-turns per pole per phase in stator and rotor is 2,400. From the curves, Fig. 6, it is seen that with a current of 700 amperes the iron bridges are sufficiently saturated. The quantity X, which determines the magnetic resistance of the slot-opening, is, according to the foregoing, for slots with slits, equal to the width of the slit, to be set at X = 0·35.

* Compare the foot-note to equation (5) on p. 249 *supra*.

The observations of the short-circuit currents for the motor under consideration are set out in Fig. 6. The no-load current amounted in the first case, with closed slots at 190 volts, 50 periods, to 80 amperes; in the second case to 100 amperes. The remaining data run :—

Motor Type 367—

$D = 90$; $\delta = 0{\cdot}11$.
$N_1 = 144$; $N_2 = 180$.
$b = 32{\cdot}5$. $P = 12$.
Slot-breadth, 11 mm.

In the first case, for a short-circuit current of 700 amperes :—

$$\sigma = \frac{100}{190} \times \frac{80}{700} = 0{\cdot}06;$$

in the second case—

$$\sigma' = \frac{80}{190} \times \frac{116}{700} = 0{\cdot}07;$$

therefore,

$$\sigma' - \sigma = 0{\cdot}01.$$

Of this difference a portion is due to the increase of the coefficient of flank-dispersion, which in the second case is increased proportional to the augmented value of the no-load current. The difference of the coefficients of flank-dispersion, for this type of motor, in accordance with the previous chapter (see Note on p. 252), amounts in both cases to :—

$$2\,(\sigma'_3 - \sigma_3) = \frac{K_3 \times 5 \times \delta}{b} \left\{1 \times \frac{100}{80} - 1\right\};$$

therefore for $K_3 = 1{\cdot}25$—

$$2\,(\sigma'_3 - \sigma_3) = 0{\cdot}0048.$$

After deduction of this difference there remains for the difference of the peripheral-dispersion the value :—

$$2\,(\sigma'_2 - \sigma_2) = 0{\cdot}0052.$$

Let us insert, according to the definition for the open slots in the formula—

$$2\,\sigma_2 = K_2 \times \frac{\delta}{N \cdot \tau} \times \frac{1}{X};$$

where $X = 0{\cdot}35$; $\delta = 0{\cdot}1$; $N = 13$; $\tau = 23{\cdot}5 \times \frac{80}{100}$ (reduced in proportion to the no-load current);

$K_2 = 1$. Hence one has—
$2\,\sigma_2 = 0{\cdot}0011$, and further—
$2\,\sigma'_2 = 0{\cdot}0041$.

The magnetic resistance of the saturated iron bridges of the closed slots is therefore about four times smaller than the resistance of the open slots.

As a second example, which shows still more clearly the pro-

portionately very small value of the so-called peripheral-dispersion, we adduce the results of a motor, Type 363, the stator of which was executed, *first*, with 96 closed slots; *secondly*, with 96 completely open slots with an opening of 13 millimetres. The slots of the second stator were arranged for the insertion of former-wound coils. The rotor had in both instances 144 slots, which in the first case were closed, in the second were slit with slits about 1 mm. wide. The iron bridges over the closed stator and rotor slots had a thickness of 0·1 mm. and a breadth of about 2 mm. The normal current of the motor amounted to about 200 amperes at 190 volts. In the first case the stator winding was carried out with two conductors per slot in star grouping; in the second case, with four conductors per slot joined in triangle grouping.

The curves, Fig. 7, depict the short-circuit currents in the two cases.

The no-load current amounted in the first case to 35 amperes at 200 volts; in the second case to 53 amperes at 200 volts. The air-gap was

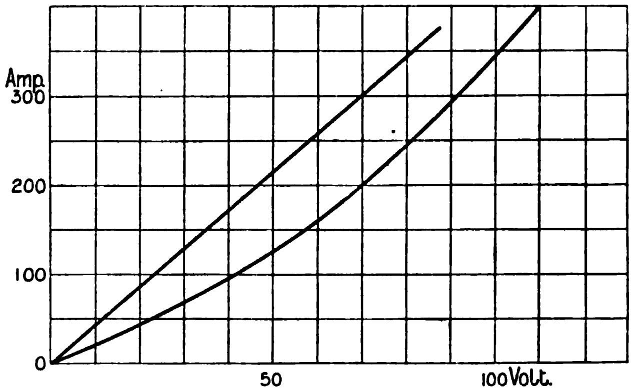

FIG. 7.

in the first case 0·9 mm.; in the second 1·1 mm. If reduced to equal length of gap, and equal numbers of conductors, the no-load current in the second case would therefore be about 1·6 times greater than in the first case. The short-circuit curve in the first case runs in a straight line from about 250 amperes. For 300 amperes one obtains, in the first case:—

$$\sigma = \frac{35}{200} \times \frac{93}{300} = 0{\cdot}054\,;$$

in the second case—

$$\sigma' = \frac{53}{200} \times \frac{70}{300} = 0{\cdot}062.$$

The dimensions of the motor are (compare the last example in Chapter III., § 1),

Motor Type 363:—With 8 poles.

$D = 58$; $b = 24$.

$N_1 = 96$; $N_2 = 144$.

Slot-breadth, 13 mm.; slot-pitch, 22·5 mm.

The magnetic resistance X of the slot-opening is in the first case considerably smaller than in the second case. But now although the value of the total dispersion-coefficient σ is larger in the second case than in the first case, the diminution of the peripheral-dispersion in the second case must be masked by an increase of the contributions to σ from other sources. In part, the dispersion-coefficient σ_3 due to flank-leakage in the second case is relatively greater in consequence of the considerably greater magnetic resistance in the second case, as evidenced by the 1·6 times greater no-load current. According to a calculation made in Chapter III., § 1, for the same motor, the value for the coefficient of flank-dispersion was found :—

$$2\,\sigma_3 = 0{\cdot}028.$$

If for the second case one raises this value in the proportion 1·6 : 1, and deducts the difference of the flank-dispersions from the observed difference of the total dispersion, then the remainder represents approximately the difference of the peripheral-dispersion in the two cases :—

$$\sigma - \sigma' = 0{\cdot}054 - 0{\cdot}062 = -0{\cdot}008\,;$$
$$2\,(\sigma_3 - \sigma'_8) = 0{\cdot}028 - (1{\cdot}6 \times 0{\cdot}028) = -0{\cdot}017\,;$$

therefore,

$$2\,(\sigma'_2 - \sigma_2) = 0{\cdot}009.$$

Putting $K_2 = 1$; $X = 1{\cdot}3$; $N = 15$; $\delta = 0{\cdot}11$; $\tau = 23 \times 0{\cdot}75$ (for τ will be reduced in proportion to the no-load current, regard being had to the different air-gaps); then we get :—

$$2\,\sigma_2 = 0{\cdot}00031, \text{ and } 2\,\sigma'_2 = 0{\cdot}009.$$

From this it follows that the magnetic resistance of the closed slots was about thirty times smaller than that of the open slots.

We adjoin the remark that there lie before us a very great number of observations on the most diverse types of motors with closed and open slots, which all indicate that the peripheral-dispersion, which depends on the magnetic resistance of the slot-opening, can in general possess only a very small value. The difference between the values of σ for the two forms of slot shows in all cases a very slight value, provided the value of σ is removed from that range of the curve of short-circuit currents in which the saturation of the iron bridges above the slots is considerable. Only when the saturation of these bridges is very low can the leakage exercise any notable influence on the value of σ.

A second mode of estimating the value of σ_2 is afforded by comparative observations on similar types of motor with different air-gaps δ, provided that for such type the amount due to flank-dispersion σ_3 has been adequately eliminated by other measurements. We adduce the following examples out of a large series :—

In a motor of Type 365 the air-gap was altered from that usual in motors of this type by a careful displacing of the slot-stampings in the iron sheets.

Motor Type 365 :—With 8 poles.

$D = 70$; $b = 30$.
$N_1 = 120$; $N_2 = 160$.
Slots closed.

In the first case $\delta = 0{\cdot}1$; in the second case $\delta = 0{\cdot}14$. Using the earlier-found constants, the contribution due to flank-dispersion was found—

$$(1) \qquad 2\,\sigma_3 = \frac{5 \times 0{\cdot}1 \times 1{\cdot}25}{30} = 0{\cdot}021.$$

$$(2) \qquad 2\,\sigma'_3 = 0{\cdot}029.$$

With the short-circuit current at saturation-value there was observed in the mean—

$$\sigma - \sigma' = 0{\cdot}009;$$

so that in both cases there may be reckoned a value of 0·001 for the difference of the peripheral-dispersions, and, therefore, for the peripheral-dispersion itself the value—

$$\sigma_2 = 0{\cdot}0025;$$

or, for $K_2 = 1$, $X = 0{\cdot}90$; therefore about four times greater than was reckoned for a slot-opening of 2 mm.

Motor Type 3072 :—With 14 poles.

$D = 150$; $b = 28{\cdot}5$.
$N_1 = 168$; $N_2 = 210$.

Slots open, with slits about 1·5 mm. wide—

$\delta = 0{\cdot}1$; $\sigma = 0{\cdot}046$;
$\delta' = 0{\cdot}14$; $\sigma' = 0{\cdot}055$;

$$2\,\sigma_3 = \frac{5 \times 0{\cdot}1 \times 1{\cdot}25}{28{\cdot}5} = 0{\cdot}022; \quad 2\,\sigma'_3 = 0{\cdot}030;$$

$$2\,(\sigma'_2 - \sigma_2) = 0{\cdot}055 - 0{\cdot}046 - (0{\cdot}030 - 0{\cdot}022) = 0{\cdot}001;$$

therefore $\sigma'_2 = 0{\cdot}0035$. Calculation gives—

$$\sigma_2 = \frac{0{\cdot}14}{0{\cdot}15 \times 13 \times 33} = 0{\cdot}0025.$$

Motor Type 368 :—With 12 poles.

$D = 94$; $b = 40$.
$N_1 = 108$; $N_2 = 144$.
Slots closed—

$\delta = 0{\cdot}04$; $\delta' = 0{\cdot}1$.

For saturation values of the no-load current—

$\sigma = 0{\cdot}040$; $\sigma' = 0{\cdot}054$;

$$2\,\sigma_3 = \frac{5 \times 0{\cdot}04 \times 1{\cdot}25}{40} = 0{\cdot}006;$$

$2\,\sigma'_3 = 0{\cdot}015$;
$2\,(\sigma'_2 - \sigma_2) = 0{\cdot}005$; $\sigma'_2 = 0{\cdot}008$.

From this we may calculate the magnetic resistance X of the closed slot—

$$X = 0{\cdot}5,$$

therefore about five times greater than for a slot-opening of 1 mm.

All the observations set forth in this chapter show a sufficient agreement of the observed results with the values calculated from the theoretical considerations of Chapter II. § 2, and lead to the inference that in the ordinary constructions of motors with open slots the part relatively contributed by the peripheral-dispersion to the total values of the dispersion-coefficient σ plays a very subordinate *rôle*, and is in any case capable of being represented by formula (5) as—

$$\sigma_2 = \frac{\delta}{2\,N\,\tau\,X}.$$

For closed slots, in which the iron bridge is made thin enough, this dispersion-coefficient may be estimated about four times greater than for slots with slits. The theoretical consideration led to a tentative difference to be expected from the ten-fold contribution for closed slots. But the dimensions of the magnetic resistances of the slot-apertures do not lend themselves to any precise determination.

§ 3. Winding-Coefficients.

After having dealt in the two preceding chapters with the two chief sources of magnetic dispersion, and having established their importance, we now finally deal with the experimental verification of the operation described in Chapter II., § 1 of the *Winding-Coefficient* σ_1. Formula (4) gives the definition—

$$\sigma_1 = \frac{1{\cdot}3\,K_1}{N^2};$$

in which the coefficient K_1 may be put as about equal to unity.

This expression is distinguished from the dispersion-coefficients σ_2 and σ_3 by its independence of the magnetic reluctance in the path of the main flux, and therefore by its independence of δ, τ, and b. Since the value of the coefficient σ_2 of the peripheral dispersion turns out, according to the previous Chapter, to be, for moderately well-proportioned motors, always considerably smaller than the sum of the other coefficients σ_1 and σ_3, it follows that the coefficient σ_1 will originate mainly from the differences of the values of σ which are found for different numbers of slots when the other dimensions remain alike.

Here a very large series of examples are afforded by all those cases in which motors of similar type, and with equal total numbers of slots, are wound for different numbers of poles. Since N denotes the number of slots in one pole-pitch, then, for a given similar total number of slots, the coefficient σ_1 is obviously proportional to the square of the number of poles.

For two different numbers of poles, in the case of the same motor, one obtains two different values of the total dispersion-coefficient σ; the difference between these values being, from formula (8), set out as—

$$\sigma - \sigma' = \mathrm{K}_1 \times 2{\cdot}6 \left(\frac{1}{\mathrm{N}^2} - \frac{1}{\mathrm{N}'^2}\right) + \frac{\delta}{\mathrm{X}} \left(\frac{1}{\mathrm{N}\,\tau} - \frac{1}{\mathrm{N}'\,\tau'}\right).$$

If Z is the total number of slots of the motor, and if $\tau = \pi\,\mathrm{D} \div \mathrm{P}$, then we have—

$$\sigma - \sigma' = \frac{\mathrm{K}_1 \times 2{\cdot}6}{Z^2} (\mathrm{P}^2 - \mathrm{P}'^2) + \frac{\delta}{\mathrm{X} \times Z \times \pi\,\mathrm{D}} (\mathrm{P}^2 - \mathrm{P}'^2).$$

If, therefore, according to the previous chapter, the second member, which shows the value of the peripheral-dispersion, is determined, the comparison of the two values of σ and σ' can afford a direct decision as to the amount of the winding-coefficient.

A second method of determining this coefficient proceeds from the circumstance that for several different positions of the rotor with respect to the stator the winding-coefficient must in general attain different values. This circumstance has long been known in practice, and indeed makes itself evident in a very unmistakable manner in the case of short-circuited rotors by the torque of the rotor, at starting, having minimum values in certain positions, so much so that in some cases the rotor has to be pushed by the application of external forces out of its position of rest into certain other positions, or also in some cases the rotor takes up a steady speed which is a fraction of the normal speed. In such motors one has frequently resorted to the expedient of increasing the total dispersion by widening the air-gap, in order to cause the relative differences to vanish compared with the total or mean value. Further, it has been the practice to arrange the slots in one part slightly oblique with respect to those of the other part, or to choose the winding-pitch differently in the two parts. Besides this, the inequality of distribution of the magnetic field here comes into play. At each pole-pitch of a three-phase motor with the usual distribution of winding, there exist, as is known, three places where the strength of the field at its maximum can be about 15 per cent. lower than it is at other places. Practice has for long dictated the advantage of choosing the ratio of the slot-numbers in the two systems as an irregular ratio in order to diminish the fluctuations of the winding-coefficients between one place and another place. A numerical estimation of the winding-coefficient is made much more difficult by the circumstance that the minimum and maximum values of σ (which are evidenced by the regular variations of the short-circuit current as the rotor is slowly turned round by hand) are such that they do not reveal exactly the absolute amount of the winding coefficient, since in general there is no position in which this coefficient vanishes.

A third more exact method of determining this coefficient is afforded by the case of motors in which, while the dimensions of

of δ, τ, b, P, and X are maintained alike, the number of slots alone is changed.

For the calculations of Chapter II., § 1, in the final formula (4), there was inserted for the mean value of σ_1 the half of the maximum value, in order to allow for the various intermediate positions between the extreme end places. In our experimental determination of σ from the short-circuit current the value of σ was, however, observed for one position only. In general this position will be that in which the mutual induction is a minimum, since the rotor generally has a very energetic tendency to remain in this position and to turn into this position. Other positions can be retained only with application of great care. We might with great probability assume* for the following observations of the short-circuit current that the short-circuit current, as measured in Chapter II., § 2, corresponds to the place denoted as the second position, and we have therefore, for comparison of the observed values with the results calculated by formula (4), to insert the maximum value for the value of the constant K_1 in that formula; K_1 having in that place, from its nature, the mean value unity. We have therefore to expect, in the comparison of results which follows, that K_1 will turn out to be of the magnitude 2.

(a) *Motors with Different Numbers of Poles.*

Motor Type 8048.

$$D = 58\,; \qquad b = 30.$$
$$\delta = 0{\cdot}07\,; \qquad X = 0{\cdot}1.$$
$$N_1 = 120\,; \qquad N_2 = 160.$$
$$Z = 140.$$
$$\begin{cases} P = 8\,; & \sigma = 0{\cdot}042. \\ P = 4\,; & \sigma' = 0{\cdot}022. \end{cases}$$

$$\sigma - \sigma' = 0{\cdot}020 = \frac{2{\cdot}6 \times K}{(140)^2}(64 - 16) + \frac{0{\cdot}07}{0{\cdot}1 \times 140 \times 180}(64 - 16).$$

The second term has the value of 0·0013, therefore approximately—

$2(\sigma_1 - \sigma'_1) = 0{\cdot}018$; from which it follows that—

$K_1 = 2{\cdot}9\,; \quad 2\sigma_1 = 0{\cdot}024.$

On the other hand, from Chapter III., § 1, for the flank-dispersion of this motor, we have—

$$2\sigma_3 = \frac{5 \times 0{\cdot}07 \times 1{\cdot}25}{30} = 0{\cdot}0146\,;$$

therefore in total,

$$\sigma = 2\sigma_1 + 2\sigma_2 + 2\sigma_3 = 0{\cdot}041,$$

while, as observed,

$$\sigma = 0{\cdot}041.$$

* More exact results one would obviously obtain in practice if the rotor were slowly revolved during the observation of the short-circuit current. For reasons of convenience this precaution was not observed in the older measurements now under consideration.

Motor Type 3066.

$D = 90; \quad b = 23.$

$\delta = 0{\cdot}1; \quad X = 0{\cdot}15.$

$N_1 = 144; \quad N_2 = 180.$

$Z = 162.$

$$\begin{cases} P = 12; & \sigma = 0{\cdot}067. \\ P = 6; & \sigma' = 0{\cdot}0328. \end{cases}$$

$$\sigma - \sigma' = 0{\cdot}035 = \frac{K_1 \times 2{\cdot}6}{(162)^2}(144 - 36) + \frac{0{\cdot}1 \times (108)^2}{0{\cdot}15 \times 162 \times 280}.$$

The second term has the value 0·0016; from which follows:—

$$K_1 = 3; \quad 2\,\sigma_1 = 0{\cdot}043.$$

The value of the flank-dispersion of this motor is—

$$2\,\sigma_3 = \frac{6{\cdot}25 \times 0{\cdot}1}{23} = 0{\cdot}028:$$

$$\sigma = 2\,\sigma_1 + 2\,\sigma_2 + 2\,\sigma_3 = 0{\cdot}073,$$

while there was observed,

$$\sigma = 0{\cdot}067.$$

Motor Type 361.

$D = 49; \quad b = 19.$

$\delta = 0{\cdot}07; \quad X = 0{\cdot}1.$

$N_1 = 72; \quad N_2 = 120.$

$Z = 96.$

$$\begin{cases} P = 8; & \sigma = 0{\cdot}064. \\ P = 4; & \sigma' = 0{\cdot}034. \end{cases}$$

$\sigma - \sigma' = 0{\cdot}030.$

The value of the second term is 0·0023; from which one gets:—

$$K_1 = 2; \quad 2\,\sigma_1 = 0{\cdot}025.$$

Motor Type 3067.

$D = 90; \quad b = 32.$

$\delta = 0{\cdot}1; \quad X = 0{\cdot}15.$

$N_1 = 144; \quad N_2 = 180.$

$Z = 162.$

$$\begin{cases} P = 12; & \sigma = 0{\cdot}060. \\ P = 8; & \sigma' = 0{\cdot}043. \end{cases}$$

$\sigma - \sigma' = 0{\cdot}017.$

The value of the differences of the peripheral-dispersion is 0·0012.
One finds $K_1 = 2; \quad 2\,\sigma_1 = 0{\cdot}029.$
For flank-dispersion $2\,\sigma_3 = 0{\cdot}020.$

$$\sigma = 0{\cdot}051; \quad \text{as observed,} = 0{\cdot}06.$$

From the foregoing examples we obtain as mean value—

$$K_1 = 2{\cdot}5 \text{ for the most unfavourable position,}$$

and for mean positions we write:—

$$2\,\sigma_1 = 3/N^2.$$

(b) We adduce two further examples in which for similar types of motor, with equal numbers of poles, the number of slots was altered.

Motor Type 360.

$$D = 38; \quad b = 24.$$
$$\delta \text{ effective} = 0{\cdot}08; \quad P = 6.$$
$$\begin{cases} N_1 = 54; & N_2 = 72; & X = 0{\cdot}2: & \text{then } \sigma \text{ (observed)} = 0{\cdot}054. \\ N_1 = 108; & N_2 = 144; & X = 0{\cdot}1: & \text{then } \sigma' \text{ (observed)} = 0{\cdot}039. \end{cases}$$

The no-load currents in the two cases were approximately alike. In the first case each slot held four conductors; in the second case, two conductors.

The difference of the peripheral leakage was reduced to zero by the slit in the slots being in the first case double as wide as in the second case.

Therefore we have :—

$$\sigma - \sigma' = 2(\sigma_1 - \sigma'_1) = 0{\cdot}022, \text{ according to the formula.}$$
$$2\sigma_1 = K_1 \times 2{\cdot}6/N^2, \text{ and according to this observation :—}$$
$$K_1 = 1{\cdot}3; \quad 2\sigma_1 = 0{\cdot}03.$$

By the earlier formulæ :—

$$\text{The flank-dispersion,} \quad 2\sigma_3 = 0{\cdot}021;$$
$$\text{The peripheral-dispersion,} \quad 2\sigma_2 = 0{\cdot}002.$$
$\sigma = 2\sigma_1 + 2\sigma_2 + 2\sigma_3 = 0{\cdot}052$; while observation gave $\sigma = 0{\cdot}062$.

Motor Type 3071.

$$D = 150; \quad b = 22.$$
$$\delta = 0{\cdot}15; \quad P = 16.$$

(i) $N_1 = 144$; $N_2 = 192$; slots closed.

$J_o = 12{\cdot}5$ amperes at 3,000 volts, 50 $\sim$, for 14 conductors in each stator slot.

$J_k = 55$ amperes (for saturated slot bridges), at 980 volts.

$\sigma = 0{\cdot}075$.

(ii) $N_1 = 192$; $N_2 = 216$; slots open, $X = 0{\cdot}25$.

$J_o = 6{\cdot}5$ amperes at 5,000 volts, 50 $\sim$, for 20 conductors in each stator slot.

$J_k = 40$ amperes at 2,000 volts.

$\sigma = 0{\cdot}065$.

The no-load current is in case (ii) 20 per cent. greater than in case (i), if both cases are reduced to the same number of conductors. Hence in case (ii) there is of necessity an increase of the coefficient of flank-dispersion. The flank-dispersion in case (i) amounts, according to the previous method of calculation, to :—

$$2\sigma_3 = 0{\cdot}043; \quad \text{and in case (ii) to } 0{\cdot}052.$$

Similarly the peripheral dispersion is in case (ii)

$$2\sigma_2' = 0{\cdot}0015.$$

If, following our earlier calculation, we estimate the peripheral-dispersion of case (*i*) as four times greater, we get—

$$2(\sigma_2 - \sigma'_2) = 0{\cdot}0045.$$
$$2(\sigma_3 - \sigma'_3) = -0{\cdot}0090.$$

Observation gave :—

$$\sigma - \sigma' = 0{\cdot}010.$$

Taking into account the differences of the dispersion-coefficients σ_2 and σ_3, one therefore has :—

$$2(\sigma_1 - \sigma'_1) = 0{\cdot}015 = K_1 \times 2{\cdot}6\left(\frac{1}{110} - \frac{1}{180}\right):$$

from which it follows that $K_1 = 1{\cdot}65$; $2\sigma_1 = 0{\cdot}039$:

$$\sigma = 2\sigma_1 + 2\sigma_2 + 2\sigma_3 = 0{\cdot}088;$$

while as observed,

$$\sigma = 0{\cdot}075.$$

From the course and results of these calculations, and the precise comparison of them with the values directly observed, a practically satisfactory agreement may, in our experience, be attained. As already stated at the outset of these researches, it not unfrequently happens that in different motors of exactly the same type with exactly similar windings the observed values of σ differ from one another by as much as 10 and even 20 per cent., and it requires, therefore, great experience to deduce admissible comparative tables from the partially contradictory observations.

According to the scientific tests and the estimations made by the author, the examples used in the researches here presented afford, in general, data of entirely substantial character; but withal it must not be straightway concluded that more fundamental and systematically elaborated series of investigations will not reveal new sources for determining the dispersion-coefficient σ. According to the previously fixed state of knowledge, and with the previously attained degree of precision of the observations, we may put together the results for motors with the ordinary winding arrangements and forms of slots in the following expression :—

$$\sigma = \frac{3}{N^2} + \frac{\delta}{X \times N \times \tau} + \frac{6\delta}{b}; \quad \dots\dots\dots \quad 9$$

where N is the mean number of slots for stator and rotor within one pole-pitch; δ the width of air-gap, which is the determining factor in the no-load current; X the value of the slit at the summit of the slot; τ the pole-pitch; and b the length of the iron core-body, all expressed in centimetres.

Values inconsistent with this final formula will occur in individual cases :—(*i*) in consequence of special influences of the neighbouring iron parts upon the parts of the windings at the flanks, (*ii*) in consequence of special arrangements of the parts of the windings at the flanks, (*iii*) in consequence of special proportions in the numbers and forms of the slots in the stator and rotor which influence the winding-coefficient (*iv*) in consequence of special dispositions of the

winding elements in the stator and rotor, which alter the uniformity of the magnetic field, (v) in consequence of particular winding-pitches of the coils in stator and rotor which affect the coefficients of self-induction and mutual induction of these elements, (vi) in consequence of diverse actions which the particular dimensions of slots and air-gap exercise upon the reluctance of the magnetic circuit of which the magnetic system of the stator and rotor consists.*

Let it be assumed that the dispersion-coefficient σ may be deduced with extreme accuracy from the constructive data, on the basis of the concluding formula, then there remains as the final task for the constructor, using this value of σ for a prescribed output and speed, with a prescribed voltage and frequency, to build a motor which shall possess the highest possible efficiency and power-factor, and a sufficient capacity for overload, and without attaining a harmful temperature-rise. Yet each single one of these conditions must in its effect on the technical quality of the motor be brought into accord with the expense in material and labour, by which success can be attained. But before all things, the motor must in its mechanical relations not be weakened by any regard to purely electrical values, nor even by any regard to the cost. In a concluding chapter the process of the calculation of a motor shall be set forth in short general steps.

IV.

BASIS FOR THE DESIGN OF MOTORS.

We shall here entirely exclude any entrance on such topics as the proportions between the weights of active and constructive material, or the relations of insulation and cooling, or the various considerations which the economical construction of much smaller or much larger, much quicker or much slower motors requires. Further, the analytical theory of the equations of currents will be assumed as known. Neglecting in this theory the ohmic resistance of the winding of the primary system, we considerably simplify thereby, as is known, the formulæ for the currents and phase-displacements. The influence of this resistance can subsequently be indicated, by introducing between the voltage of the mains and that at the terminals of the motor, a drop of potential due to an equivalent non-inductive resistance equal to the actual resistance of the primary winding. Accordingly we insert as the terminal voltage of the motor the voltage of supply reduced by the amount of this drop. In that which follows we shall calculate with this reduced value, and all the strengths of currents and phase-displacements will be correlated with this value of the terminal voltage. In the diagram, Fig. 8, we denote the reduced terminal voltage of the motor by E, the current by J, the phase-angle between E and J by ϕ,

* The new winding-system applied by the Oerlikon Co. to its motors with variable numbers of poles has contributed some very interesting new points to the theory of the winding-coefficient, and its dependence upon the shortening or lengthening of the winding-pitch. The author reserves for the present the publication of this matter.

the ohmic resistance by r_1, the voltage-drop Jr by e; so then we obtain the connexion between the voltage of the supply mains E_o, that of the reduced voltage E, and the current J directly from the figure.

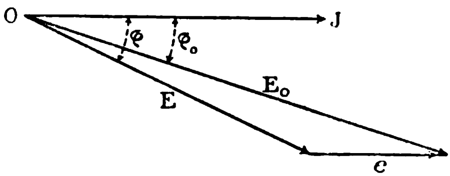

FIG. 8.

We designate by S the slip of the motor, by r_2 the ohmic resistance of one phase of the secondary system, by m the transformation-ratio of the windings of the primary and secondary systems. J_o denotes the magnetising current, which, for simplicity, we will regard as coincident with the no-load current. An expression which often recurs in the theory we will write, for brevity—

$$\frac{S\,E}{J_o\,r_2\,m^2} = a.$$

Then we have for the primary current—

$$J_1 = J_o \frac{\sqrt{1 + a^2}}{\sqrt{1 + a^2\,\sigma^2}}; \quad \ldots\ldots\ldots \quad (1)$$

for the secondary current—

$$J_2 = J_1 \times m \times a \frac{\sqrt{1 - \sigma}}{\sqrt{1 + a^2}}: \quad \ldots\ldots \quad (2)$$

and—

$$\cos\phi = \frac{a\,(1 - \sigma)}{\sqrt{1 + a^2 + \sigma^2\,a^4}}. \quad \ldots\ldots\ldots \quad (3)$$

For a rapid determination of the characteristic curves of the motor we discriminate the following five cases, which correspond directly to five points on the load-curve, and which suffice in general to characterise the motor with certainty:—

First Point—

$$\left.\begin{array}{l} a = 0 \\ J_1 = J_o \\ J_2 = 0 \\ S = 0 \end{array}\right\} \quad \ldots\ldots\ldots \quad (4)$$

If there is a very small load of the amount of the no-load losses A_o, then there is further given the relation—

$$\cos\phi_o = \frac{A_o}{3\,E\,J_o}.$$

Second Point—

$$\left.\begin{array}{l} a = \dfrac{1}{2\sqrt{\sigma}}; \\ J_1 = \dfrac{J_o}{2\sqrt{\sigma}}(1 + 1{\cdot}9\sigma); \\ \cos\phi = 1 - 3{\cdot}12\,\sigma \\ S = \dfrac{r_2 J_o\,m^2}{2\sqrt{\sigma}\,E}. \end{array}\right\} \quad \ldots\ldots\ldots \quad (5)$$

σ^2 will be in general negligibly small relatively to unity.

The input of power is :—

$$A = 3\,E\,J_1 \cos\phi = \frac{3\,E\,J_o(1 - 1\cdot2\,\sigma)}{2\sqrt{\sigma}}.$$

The torque developed, including that which is used in producing the no-load work (friction, etc.) is in kilogrammetres :—

$$D = \frac{A}{T_o \times 1\cdot03};$$

where T_o signifies the no-load speed.

Third Point—

$$\left.\begin{aligned} a &= \frac{1}{\sqrt{\sigma}}; \\ J_1 &= \frac{J_o}{\sqrt{\sigma}}; \\ \cos\phi &= 1 - 2\,\sigma; \\ A &= \frac{3\,E\,J_o}{\sqrt{\sigma}}(1 - 2\,\sigma); \\ S &= \frac{r_2\,J_1\,m^2}{E} \end{aligned}\right\} \quad \ldots\ldots\ldots \quad (6)$$

This point gives the load with maximum power-factor. Now a rationally-built motor will obviously be so dimensioned that its normal load approximately corresponds to this point, always provided that the conditions of capacity for overload do not conflict with it.

Fourth Point—

$$\left.\begin{aligned} a &= \frac{1\cdot5}{\sqrt{\sigma}}; \\ J_1 &= \frac{1\cdot5\,J_o}{\sqrt{\sigma}}(1 - 2\,\sigma); \\ \cos\phi &= 1 - 2\cdot3\,\sigma; \\ S &= \frac{J_1\,r_2\,m^2}{E(1 - 2\,\sigma}; \\ A &= \frac{3\,E\,J_o}{\sqrt{\sigma}} \times 1\cdot5(1 - 4\cdot6\,\sigma) \end{aligned}\right\} \quad \ldots\ldots\ldots \quad (7)$$

Fifth Point—

$$\left.\begin{aligned} a &= \frac{1}{\sigma}; \\ J_1 &= \frac{J_o}{\sqrt{2\,\sigma}}; \\ \cos\phi &= \frac{1 - \sigma}{\sqrt{2}}; \\ S &= \frac{J_o\,r_2\,m^2}{\sigma\,E}; \\ A &= \frac{3\,E\,J_o}{2\,\sigma}(1 - \sigma) \end{aligned}\right\} \quad \ldots\ldots\ldots \quad (8)$$

This point corresponds to the maximum torque which the motor can exert.

If we denote by D the torque which corresponds to the third point, at ideal normal load, then the maximum torque D_m is related to the normal torque according to the expression :—

$$\frac{D_m}{D} = \frac{1 + \sigma}{2\sqrt{\sigma}} = y \quad \ldots\ldots\ldots \quad (9)$$

This is the maximum capacity for overload of a motor whose normal load corresponds to the third point.

The torque at the second point is very nearly equal to the half of the torque of third point, and that at the fourth point nearly 1·5 times that of the third point.

Now these five points determine the characteristic performance of the motor with adequate precision so far as practical design is concerned. For this purpose the influence of the primary resistance can easily be subsequently taken into account as a correcting term by reference to Fig. 8, since the voltage E used in the formulæ may be reckoned from the supply voltage E_o and the voltage-drop e. So long as e is small in comparison with E, then from the figure we have approximately:—

$$\left.\begin{aligned} E &= E_o - J_1\, r_1 \cos\phi\,; \\ \cos\phi_o &= \cos\phi + \sin^2\phi\,\frac{J\, r_1}{E}\,; \end{aligned}\right\} \quad \cdots \quad (10)$$

The current J_o must be reckoned with respect to E.

We may remark also a correction for the coefficient σ. When σ is to be calculated from the no-load current J_o and the current J_k of the short-circuited motor, then with an accuracy of first order we obtain the formula:—

$$\sigma = \frac{J_o}{J_k}\sin\phi_o\left\{1 - \frac{J_k^2}{E^2}\left(\frac{r_2^2\, m^4}{2} + r_1\, r_2\, m^2\right)\right\}. \text{ In practice } \sigma = \frac{J_o}{J_k}.$$

If we assign to the torque which corresponds to the third point the value 1, as being normal, the current at this point as the normal current J, and the corresponding slip at this load as S, then we may conveniently assemble the values for the five points in the following Table:—

POINT.	TORQUE.	CURRENT.	POWER-FACTOR.	SLIP.
1	$\frac{a_o}{T_o}$	J_o	$\frac{a_o}{3E\,J_o}$	0
2	$\frac{1 + 0{\cdot}8\,\sigma}{2}$	$\frac{J}{2}(1 + 1{\cdot}9\,\sigma)$	$1 - 3{\cdot}12\,\sigma$	$\frac{1}{2}$S
3	1	J	$1 - 2\,\sigma$	S
4	$1{\cdot}5\,(1 - 2{\cdot}6\,\sigma)$	$1{\cdot}5\,J\,(1 - 2\,\sigma)$	$1 - 2{\cdot}3\,\sigma$	$1{\cdot}5\,\frac{S}{1 - 2\sigma}$
5	$\frac{1 + \sigma}{2\sqrt{\sigma}}$	$\frac{J}{\sqrt{2}\,\sqrt{\sigma}}$	$\frac{1 - \sigma}{\sqrt{2}}$	$\frac{S}{\sqrt{\sigma}}$

The determination of these five points requires only a knowledge of the total dispersion-coefficient σ, the no-load losses and the magnetising current J_o. If the efficiency also is prescribed, then the resistances r_1 and r_2 must be calculated.

The magnetising current J_o can only be exactly calculated if the numbers and dimensions of the slots are known in addition to the principal dimensions and winding data. The dependence of the exact distribution of the magnetic field upon the number of slots has been repeatedly discussed by others. The influence on the magnetising current of a voltage curve which departs from the simple sine form will not be here regarded.

EXAMPLE I.—*To find the characteristic curves of a 4-pole 5-HP. motor,* of which we have observed the following data :—

At no-load, with $E = 200$ volts; $J_o = 2$ amperes; $U = 1500$ revolutions. per minute, at frequency $f = 50 \sim$; input $= 200$ watts.

At short-circuit, with $E = 100$ volts; $J_k = 23$ amperes; frequency $f = 50 \sim$; $r_1 = 0{\cdot}5$ ohm; $r_2 = 0{\cdot}1$ ohm; $m = 2$.

First we calculate σ.

$$\sigma = \frac{2}{200} \times \frac{100}{20} = 0{\cdot}05.$$

(We here neglect the small correction of σ due to the resistances r_1 and r_2, which can only alter the value of σ by 1 per cent.)

Next we determine the third point of the Table. The maximum power-factor is such that $\cos\phi = 1 - 2\sigma = 0{\cdot}9$; and the corresponding intensity of current is $J = J_o / \sqrt{\sigma} = 9$ amperes. This current will give a torque of—

$$D = \frac{3 \times 200 \times 9 \times 0{\cdot}9}{1{\cdot}03 \times 1500} = 3{\cdot}15 \text{ kilogrammetres.}$$

The slip is—

$$S = \frac{0{\cdot}1 \times 9 \times 4}{200} = 1{\cdot}8 \text{ per cent.}$$

The loss in the primary copper is $3 J^2 r_1 = 121$ watts.

The efficiency is—

$$\frac{3 \times 200 \times 9 \times 0{\cdot}9 \times (1 - 0{\cdot}018)}{(3 \times 200 \times 9 \times 0{\cdot}9) + 200 + 120} = 0{\cdot}92.$$

The other points of the Table are calculated as multiples of this third point, and give the following result :—

POINT.	TORQUE. Kilogrammetres.	CURRENT. Amperes.	POWER-FACTOR. $\cos\phi$.	SLIP. Percentage.	EFFICIENCY. Percentage.
1	0·13	2	0·18	0	0
2	1·56	5	0·85	0·9	90
3	3·15	9	0·90	1·8	92
4	4·1	12·2	0·88	3	91
5	7·4	28·2	0·67	8	86

These values of torque, current, power-factor, and efficiency, are calculated without taking into account the drop of voltage due to the primary resistance r_1. Now we have to correct these values in accordance with the diagram Fig. 8 and formula (10). The corrected Table is as follows :—

Point.	Torque.	Current.	Power-Factor.	Slip.	Efficiency.
1	0·13	2	0·18	0	0
2	1·5	5	0·852	0·92	90
3	3·0	8·8	0·905	1·87	92
4	3·9	11·9	0·886	3·15	91
5	6·8	27	0·74	8·6	86

For larger motors these corrections are obviously much smaller, since the loss in the primary copper is relatively smaller.

A few further formulæ are needed to complete the set for the calculation of motors.

The magnetising current of three-phase motors can be estimated, with a precision practically sufficient for the purpose of design, from the expression—

$$J_o = \frac{\delta \times B}{1·3\ W}; \qquad (11)$$

where δ is the air-gap, W the number of conductors of one phase within one pole-pitch, and B the value of the amplitude of the maximum flux-density in the gap. In this expression there is assumed a customary width of aperture of slots, and in addition an increase of the magnetic resistance of the air-gap due to the iron teeth, amounting to about 20 per cent. If we denote by F the useful flux through one pole-pitch, and by D the diameter of the bore, then B is defined* by the equation—

$$B = \frac{3 \times F\ P}{2 \times \pi\ D\ b}; \qquad (12)$$

$$F = \frac{E \times 10^8}{2·2 \times f\ P\ W}; \qquad (13)$$

where f is the frequency—

$$P\ F = \frac{A' \times 10^8}{1·1 \times U \times J\ L_o}; \qquad (14)$$

where A′ is the product of the volts and amperes which the motor takes at normal load; U the peripheral speed, in centimetres per

* The highest saturation may, for example with 15 slots per pole-pitch, be 20 per cent. greater than this.

$\frac{\Delta}{\times N \times \tau} + \frac{6\Delta}{b}$. AND BY BEHREND'S FORMULA $\sigma = C\frac{\Delta}{\tau}$, WITH THE OBSERVED VALUES OF σ FOR 31 OERLIKON

15 $\frac{\Delta}{X \times N \times \tau}$	16 $\frac{6\Delta}{b}$	17 σ from Dr. Behn-Eschenburg's formula:— $\sigma = \frac{3}{N^2} + \frac{\Delta}{X \times N \times \tau} + \frac{6\Delta}{b}$.	18 σ from Behrend's Formula:— $\sigma = C\frac{\Delta}{b}$, in which C is determined from Fig. 1.	19 Observed Value of σ.	20 Disagreement between the Values in Columns 17 and 19 Expressed in Per Cent. of Observed Value.	21 Per Cent. Disagreement between the Values in Columns 18 and 19, in Per Cent. of Observed Value.
·0014	·039	·0472	·0455	·06	21	24
·0031	·039	·0574	·0620	·09	36	31
·0014	·027	·0351	·0420	·045	22	7
·0031	·027	·0453	·0565	·075	40	25
·0020	·0252	·0389	·0439	·050	22	12
·0035	·0252	·0495	·0542	·063	21	14
·0020	·0171	·0308	·0392	·042	27	7
·0035	·0171	·0414	·0490	·056	26	12
·0030	·035	·0548	·0600	·067	18	10
·0030	·015	·0348	·050	·046	24	9
·0026	·0237	·0397	·0495	·054	26·5	8
·0050	·0205	·0422	·0583	·070	39	16·5
·0015	·0205	·0385	·0480	·060	36	20
·0053	·0225	·0411	·0525	·054	24	2·5
·00085	·0275	·0417	·0418	·062	32·5	32·5
·0021	·0200	·0320	·0461	Not given	—	—
·0030	·0280	·0409	·0646	Not given	—	—
·0015	·0210	·0390	·0387	·046	15	15
·0020	·0295	·0480	·0542	·055	13	1·5
·0030	·0060	·0362	·0202	·040	0	45
·0030	·0150	·0452	·0505	·054	16	6
·0018	·0140	·0257	·037	·042	39	12
·0004	·0140	·0169	·022	·022	23	0
·0021	·0260	·0446	·055	·067	33	18
·0005	·0260	·0306	·032	·0328	6	2
·0030	·0221	·0459	·0466	·064	28	27
·0008	·0221	·0281	·0273	·034	17	20
·0021	·0188	·0374	·0500	·060	37	16
·0009	·0188	·0270	·0365	·043	37	15
·0019	·0200	·0491	·0475	·054	9	12
·0019	·0200	·0287	·0456	·039	27	19
·0097	·0408	·0777	·0745	·075	3	1
·0016	·0408	·0607	·0670	·065	7	3
					725	443
				Average Disagreement =	23·4 %	14·3 %

ESTI IGS. 1 & 2 RESPECTIVELY) AND COMPARISON OF
BEHN-ESCHENBURG'S PAPER.

Ref Nu	C' from Fig. 2.	σ from Behrend's Formula: σ=C C'	Observed Value of σ.	Per Cent. disagreement between estimated and observed values of σ, in per cent. of observed values.
	1·08	0·049	0·060	18
	1·29	0·080	0·090	11
	1·08	0·045	0·045	0
	1·29	0·073	0·075	3
	1·11	0·049	0·050	2
	1·25	0·068	0·063	8
V	1·11	0·044	0·042	5
V	1·25	0·061	0·056	9
	1·09	0·065	0·067	3
	1·09	0·054	0·046	17
	1·09	0·054	0·054	0
	1·08	0·063	0·070	10
	1·08	0·052	0·06	13·5
	1·09	0·057	0·054	6
	1·01	0·052	0·062	16
X	1·09	0·042	0·046	8·5
	0·96	0·052	0·055	6
	2·05	0·041	0·040	3
	1·2	0·061	0·054	13
X	1·13	0·042	0·042	0
X	0·87	0·0194	0·022	12
X	1·09	0·06	0·067	10·5
X	0·84	0·027	0·033	18
X	1·35	0·063	0·064	2
X	1·0	0·027	0·034	21
XX	1·09	0·055	0·06	8·5
X	0·93	0·034	0·043	21
X	1·35	0·064	0·054	19
X	1·0	0·046	0·039	18
X	1·02	0·077	0·075	3
XX	0·95	0·064	0·065	2

Average disagreement = 8·9%

second; and $J L_o$ is the "specific load," or number of ampere-conductors per centimetre of periphery. This formula (14) is an important and very practical formula for electric machines of all types; but for continuous-current machines the coefficient 1·1 may be replaced by 1.

If now the problem is put of designing a motor for an output of A watts, with P poles, f cycles per second, then the product of volt-amperes A′, which the motor at normal load will take, is given with close practical approximation by—

$$A = A' \times \eta \times \cos \phi.$$

The normal current corresponding to A′ is—

$$J = \frac{A'}{3\,E};$$

so the problem is so to build the motor that the normal load is coincident with the load at the maximum power-factor. Then we must have—

$$J_o = J \times \sqrt{\sigma}. \quad \ldots \ldots \ldots \quad (15)$$

The weight and size of the motor is fairly determined by the total flux P F; and, by formula (14), this is so much the smaller the greater the peripheral velocity, and the greater the number of ampere-conductors per centimetre of periphery.

By transposition of formula (12) we have—

$$P F = \tfrac{2}{3}\,\pi\, D\, b\, B. \quad \ldots \ldots \ldots \quad (16)$$

For reasons of construction it is in general not possible to arrange more than 300 ampere-conductors in 1 centimetre of periphery, and, moreover, mechanical difficulties do not admit of a peripheral speed exceeding 4,000 centimetres per second. The gap-density B is limited by the saturation of the teeth, which ought not to exceed the limit beyond which the magnetising current increases faster than the flux-density. In order to afford a large winding space in the slot the teeth must be kept narrow. The air-gap δ must, for mechanical reasons, not be made less than about $\frac{1}{1000}$ of D. We will design the motor with the moderate values: $U = 1{,}500$, $J L_o = 150$, for motors of less than 10 H.P.; and $U = 2{,}500$, $J L_o = 250$ for motors exceeding 100 H.P. Then we at once can arrive at P F, and from it at the product b B. Having $J L_o$ and U, W is determined. But, according to formula (11), W and B are connected with one another by the prescribed no-load current J_o, and so all the dimensions are thus determinate.

From the earlier discussion respecting σ it is known that σ distinctly decreases as the number of slots is increased; but a large number of slots can in general be accommodated only in a large pole-pitch; and further, σ diminishes as b the core-length is increased. One part of σ which depends on the number of slots amounts, for a mean number of slots—say 12—per pole, to about 2 per cent. An increase of the number of slots may involve difficulties. Another part of σ which

depends on b has been shown to be equal to $6\delta \div b$; therefore for $\delta = 0{\cdot}1$, it follows that we must have $b = 30$ if this part of the dispersion is to have a value equal to that of the first part. Now by changing the dimensions here and there, and balancing the difficulties and profits of one alteration in the dimensions against those of another, we find by successive approximations the most economic value of σ.

We now come to the point how to estimate beforehand values of the density B that shall be favourable.

The pole-pitch τ is equal to $\pi D \div P$. If L_o stands for the number of conductors per centimetre of periphery, and W the number of conductors, *in one phase*, per pole, then—

$$W = \frac{L_o \pi D}{3 P}.$$

Now in order to be able to arrange a suitable number of ampere-conductors in a large number of slots, one will choose τ not less than 20 cm. And since, further, $\tau = U \div 2f$, it follows that for ordinary frequencies where f is from 40 to 50 cycles per second, τ must not be more than about 30, otherwise the peripheral speed may be inconveniently high. As a good mean value, we may put for small motors $\tau = 15$, for large motors $\tau = 25$.

Then from the earlier formulæ (11) and (15), we obtain :—

$$B = \frac{0{\cdot}43 \times \sqrt{\sigma} \times J L_o \times \tau}{\delta} \quad . \; . \; . \; . \; . \; . \; . \; (17)$$

Inserting for $J L_o$, δ, and σ as mean values for small motors not exceeding 10 HP., $J L_o = 150$, $\delta = 0{\cdot}05$, and $\sigma = 0{\cdot}05$; for large motors $J L_o = 250$, $\delta = 0{\cdot}1$, and $\sigma = 0{\cdot}04$, we have, as mean value :—$B = 5000$. This is a good average figure which may serve as a trial-value in design.

From formulæ (14) and (16) the peripheral surface of the motor will then be :—

$$\pi D b = \frac{3 \times A' \times 10^8}{2{\cdot}2 \times U \times J L_o \times 5000} \quad . \; . \; . \; . \; . \; . \; . \; (18)$$

And using the same mean values as before, we have :—

$$D b = \frac{5{\cdot}5 A'}{100 \pi}.$$

EXAMPLE II.—*To design a motor to fulfil the following specification* :—

To give 5 HP. actual output at 1500 revolutions per minute, the frequency being 50 $\sim$; $\cos\phi$ to be not less than $0{\cdot}9$; the efficiency at normal full-load to be not less than $\eta = 0{\cdot}9$; capacity of overload $y = 2$; the voltage in one phase to be $E = 400$ volts.

The maximum power-factor $\cos\phi = 0{\cdot}9$ is obtained by making $\sigma = 0{\cdot}05$ (*see* Example I.). Further, $y = 1 / 2\sqrt{\sigma} = 2{\cdot}25$. The normal full-load current to meet the specification will be—

$$J = \frac{5 \times 746}{3 \times 400 \times 0{\cdot}9 \times 0{\cdot}9} = 3{\cdot}83 \text{ amperes.}$$

Now the magnetising current J_o is determined by the condition :

$$J_o = J \times \sqrt{\sigma} = 0{\cdot}86 \text{ ampere.}$$

For motors of a size so small as this, we apply in designing the mean values :—

$U = 1500$ cm. per sec. ; $J\,L_o = 150$ amps. per cm. ; $\delta = 0{\cdot}05$ cm.

We will take $D = 20$ cm. Formula (17) gives $B = 4200$.

To fulfil formula (11), we calculate as number of stator conductors per phase per pole—

$$W = \frac{0{\cdot}05 \times 4200}{0{\cdot}86 \times 1{\cdot}3} \cong 180.$$

By formula (13) we have for the flux from one pole :—

$$F = \frac{400 \times 10^8}{4{\cdot}4 \times 50 \times 2 \times 180} = 0{\cdot}50 \times 10^6.$$

By formula (12) the length of the iron core-body will be :—

$$b \cong \frac{0{\cdot}50 \times 10^6 \times 3}{2 \times 4200 \times 15{\cdot}6} \cong 12.$$

Number of slots in the stator $= 60$,
" " in the rotor $= 72$;
Pitch of the slot in the stator $= 10{\cdot}4$,
" " in the rotor $= 8{\cdot}7$;
Number of conductors in one stator slot $= 36$;
Section of each stator conductor, $1{\cdot}2$ sq. mm.
Dimensions of stator slot, 6×25 mm.
Saturation of iron core $B = 7000$.
External diameter of the stator core $= 330$ mm.
Weight of the stator iron will be 48 kilogs.
Mean length of one primary conductor $= 320$ mm.

Resistance of one phase of the primary.—

$$r_1 = \frac{4 \times 180 \times 0{\cdot}32}{55 \times 1{\cdot}2} = 3{\cdot}4 \text{ ohm.}$$

Loss in the primary copper $= 3 \times 3{\cdot}4 \times (3{\cdot}8)^2 = 137$ watts.
Rotor copper loss, estimated at 70 watts.
Iron and friction losses (at about 5 watts per 1 kilog. iron) estimated at 250 watts.

Efficiency at full load $\eta = \dfrac{3700}{3700 + 457} = 89$ per cent.

Now we take the following controlling test of our design :—

We calculate $JL_o = \dfrac{12 \times 180 \times 3{\cdot}8}{20 \times \pi} \cong 136$;

$$U = \frac{20 \times \pi \times 1500}{60} = 1550.$$

By formula (14)—

$$P F = \frac{5 \times 746}{0.8 \times 1.1 \times 155 \times 136} \cong 2.0 \times 10^6.$$

$$F = 0.5 \times 10^6,$$

in accordance with the value given previously.

From formula (9) we should obtain for this motor the coefficient σ as follows:—

$$N = 16; \quad b = 12; \quad \delta = 0.05$$
$$X = 0.1; \quad \tau = 15.6;$$

whence, finally:—

$$\sigma = \frac{3}{(16)^2} + \frac{0.05}{0.1 \times 16 \times 15.6} + \frac{6 \times 0.05}{12} = 0.04;$$

which value for the dispersion-coefficient is distinctly lower than that which we found above would suffice, so that the motor will amply fulfil the specification.

Dr. Drysdale.

Dr. C. V. DRYSDALE: I think that the thanks of British electrical engineers are most heartily due to Dr. Behn-Eschenburg for the very valuable information contained in this paper, and for so freely giving us the results of a very considerable amount of labour and experience. There are two papers in recent years which have been most welcome in this respect, that of Herr Lasche at the Glasgow Electrical Congress, and the one now under consideration, and I venture to think that if British engineers would only carry out investigations in the same scientific manner and bring them forward in the same spirit as the authors of these papers and the Germans in general have done, our industry would be much improved thereby. We have heard a considerable amount recently about British trade depression, and very possibly this may be to a considerable extent due to fiscal conditions, but, to my mind, there can be no doubt that one considerable factor in this depression is the extremely conservative attitude taken by British manufacturers in attempting to keep from their rivals any information they may obtain.

Coming now to the paper itself, it seems a little unfortunate that Dr. Behn-Eschenburg has not given us a little more detailed information as to the carrying out of the tests on these induction motors. No doubt Dr. Behn-Eschenburg has considered it unnecessary to give such details, but in view of the one or two discussions we have had at this Institution on alternate-current testing, there can be no doubt that information on these points is desirable. I fail to understand Dr. Behn-Eschenburg's reason for the statement contained in the footnote on page 254, in which he contends that the transformation ratio method of obtaining the values of the dispersion is very inexact and inconvenient. At the Northampton Institute we have made several tests of magnetic dispersion on alternate-current motors by both the transformation ratio or voltmeter method, and the method of determining the no-load and short-circuit currents used by Dr. Behn-Eschenburg, and of the two methods we have come to the decided opinion that the former is preferable both for convenience and accuracy. Appended below are the results of some tests made in the Electrical Engineering

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Laboratory of this Institute by these methods, but I will here mention what appear to me to be the relative advantages and disadvantages of the two.

For the ratio or voltmeter method, all that is required is a single hot-wire or electrostatic voltmeter, or possibly two voltmeters, the potential differences being taken on each of the three phases of stator and rotor. This is done first with the stator excited, secondly with the current applied to the rotor slip-rings. The ratio of the mean P.Ds. on the stator and rotor being taken both in the first and second cases, we have $\frac{V_S}{V_R} = \frac{L_1}{M_1} = \frac{N_1 N_2}{N_1 u_1} = \frac{1}{m u_1}$, where m is the transformation ratio $\frac{N_1}{N_2}$ and u_1 the coefficient of stator leakage.* Similarly $\frac{V'}{V'_S} = \frac{m}{u_2}$ and $\sigma = 1 - \frac{1}{u_1 u_2} = \frac{u_1 u_2 - 1}{u_1 u_2} = 1 - \frac{V_S\, V'_R}{V_R\, V'_S}$. The accuracy of the voltmeter, or voltmeters, is not of serious importance, as the readings are taken at about the same part of the scale in both experiments. On the other hand, in using the current method it is necessary to have three ammeters in the three-stator phases, as few induction motors are so well balanced as to admit of reading of one phase only, and it is not possible to transfer a single ammeter from phase to phase. Next, as in any good motor the short-circuit current is from fifteen to thirty times the no-load current, it is necessary to use three different instruments for this determination, as no commercial instrument has more than a tenfold range. In addition to this, the large current obtained with short-circuit gives rise to considerable heating if any time is taken over the operations, and Dr. Behn-Eschenburg himself admits that in many cases the short-circuit current was obtained without rotation of the rotor, which is of material importance. Finally, according to the generally adopted theory of the induction motor, Dr. Behn-Eschenburg's statement that the coefficient σ is the ratio of the no-load to the short-circuit current is not strictly correct, as the no-load current should be corrected for the energy component utilised for the core loss, which must be separately observed on a wattmeter. This necessity is referred to later in the paper.

The following are some tests on two 3-phase motors in the Electrical Engineering Laboratory of the Northampton Institute. These motors are of three-brake horse-power each, and were made by the Algemeine Elektricitäts Gesellschaft; they are known as the K.D. 30 type, and are intended to run on a 3-phase 50-period circuit at 1,500 revolutions, with 60 volts between lines. Although these motors are small, the results obtained from them may be of interest, as they give an opportunity of checking Dr. Behn-Eschenburg's conclusions on another make of motors.

Fig. A shows the dimensions of the stator and rotor iron. Both the stator and rotor are slotted, the slots having projecting teeth very nearly conforming to the statements in the paper before us. The total

* This takes no account of breadth coefficients, but as these only modify the transformation ratio m which cancels the reasoning is valid.

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number of slots in the stator and rotor are 48 and 60 respectively; or four and five slots per phase per pole, while the number of conductors per slot is, as far as can be ascertained, eleven in the stator and eight in the rotor, the windings in each case being hemitropic and star-connected with two coils in parallel. We therefore have 88 conductors in series per phase in the stator and 80 for the rotor, the transformation ratio thus being $\frac{1}{1 \cdot 1}$. The breadth coefficients for the two windings come out at ·9576 and ·9566 respectively, so that the transformation ratio is not appreciably affected.

Tests were first made of the voltage ratios, and as these ratios were so nearly unity, the same hot-wire voltmeter was used for all tests. The following table shows the results, the rotor being turned between each set of tests so as to revolve approximately through a right angle between the first and last.

3-PHASE MOTOR K.D. 30. No. 90,210.

Stator Excited.							
STATOR VOLTAGES.				ROTOR VOLTAGES.			
1	2	3	Mean.	1	2	3	Mean.
65	63·3	65·1	64·5	55·6	57·5	56·7	56·6
65	63·1	65·1	64·4	55·2	56·7	57·2	56·4
64·9	63	65·2	64·4	55·3	56	57·3	56·2
64·9	63	65·2	64·4	55·8	56	57·7	56·2
64·9	62·9	65·3	64·4	56·6	55·3	57·7	56·5
64·9	63	65·2	64·4	57·5	55·5	56·4	56·5
64·9	63	65·2	64·4	57·5	56	55·5	56·3
Rotor Excited.							
60·7	59·3	59·5	59·8	55·2	56·3	56·2	55·9
60·5	59·2	60·3	60·0	55·3	56·4	56·5	56·1
59·9	59·6	61	60·2	55·4	56·4	56·6	56·1
59·3	60·1	61	60·1	55·3	56·4	56·5	56·1
59·4	61	60	60·1	55·2	56·4	56·5	56·0
60	60·9	59·4	60·1	55·3	56·5	56·6	56·1

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Taking the average of these figures, and correcting the voltmeter readings, we get—

$$\frac{M_1}{L_1} = \frac{V_R}{V_S} = \frac{56 \cdot 4}{64 \cdot 4} = \cdot 876 \text{ and } \frac{M_2}{L_2} = \frac{V_S'}{V'} = \frac{60 \cdot 05}{56 \cdot 05} = 1 \cdot 071,$$

from which $$\frac{M_1 M_2}{L_1 L_2} = \cdot 938 \text{ and } . \sigma = \cdot 062,$$

the coefficients of stator and rotor leakage both coming out at 1·028.

A similar set of tests being made with the second motor No. 61,802 resulted in a value of σ of $1 - \cdot 878 \times 1 \cdot 073 = \cdot 058$, which agrees fairly well with that obtained in the first case.

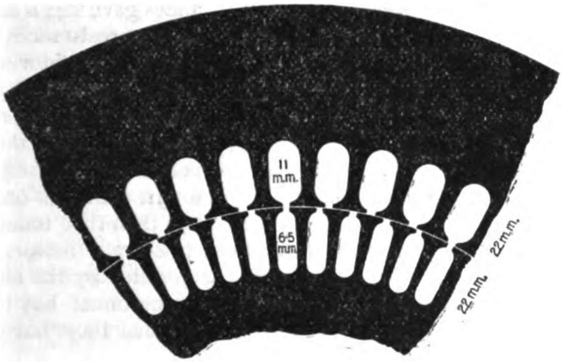

FIG. A.—Stampings of 3 B.H.P. 3-Phase A.E.G. Motor. Type K.D. 30.

Internal Diameter of Stator	...	215 mm.
External " Rotor	...	214 "
Gap	...	0·5 "
Opening of Stator Slots	...	3·0 "
" " Rotor "	...	2·7 "
Length of Core	...	83·5 "

On making tests on the former machine by the short-circuit current the diagram Fig. B shows the results and the value of $\sigma = \frac{6}{92} = \cdot 0653$. The rotor was not revolved during these tests, but a rough trial showed that variations of some three or four per cent. would have been caused by this. As an instance, however, of the necessity of taking the currents in each of the phases separately, it may be mentioned that a typical result for the light-load currents in the three phases was 6·3 amperes, 7·6 amperes, and 9·3 amperes respectively. I am inclined to attribute this to some extent to the rotary converter from which current was supplied.

The value of σ given by the current test above is higher than that with the voltage test, but it was found that the motor when running

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light at 9 amperes per phase absorbed 248 watts, the power-factor being ·254. The value of σ hence should equal ·0653 $(1 - {·254}^2) =$ ·063, a value agreeing very nearly with that (·062) obtained by the voltmeter tests.

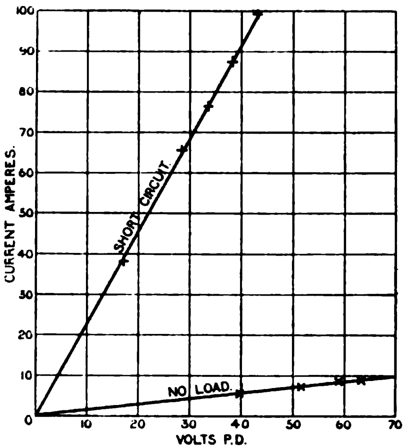

FIG. B.—No-Load and Short-Circuit Currents for 3-Phase Motor.

The Heyland diagram for the motor is given in Fig. C. According to the usual formula, the maximum power-factor of the motor should be ·88, but the value actually obtained was about ·92. Measurements of the resistances gave ·044 ω and ·0414 ω, as the resistances of each arm of the stator and rotor. Correcting the Heyland diagram for the stator resistance, we find that the power-factor is increased from ·88 to ·91, which is only slightly less than that found by measurement. We have tested a few alternate-current motors on other occasions in which the power-factor has been stated by the makers, and in each case the power-factor obtained by experiment has been some 3 or 4 per cent., or more, in excess of the value they have given us from the Heyland diagram.

The great value of Dr. Behn-Eschenburg's paper lies, of course, in the formulæ he has so carefully obtained for the prediction of the dispersion coefficient from the dimensions of the machine. I have therefore applied the formula No. 9, p. 268, to the above motor, for which N the mean number of stator and rotor slots per pole

$$= \frac{12 + 15}{2} = 13·5, \quad X = \frac{·3 + 2·7}{2} = ·285, \quad \tau = \frac{67·5}{4} = 16.8,$$

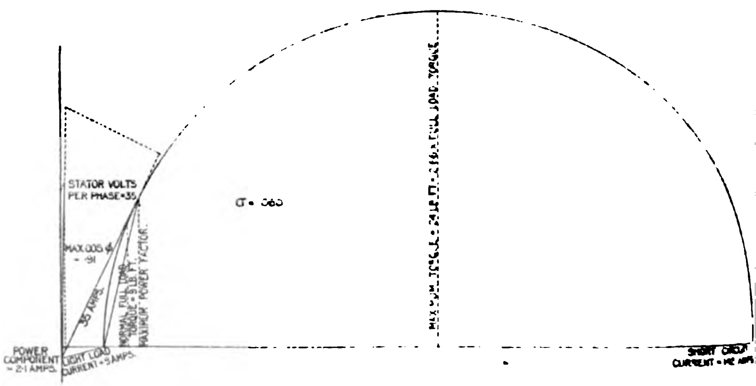

FIG. C.—Heyland Diagram for 3 B.H.P. 3-Phase A.E.G. Motor.

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or corrected for width of openings,

$$= 16{\cdot}8 - 13{\cdot}5 \times {\cdot}285 = 13, \quad \delta = {\cdot}05, \quad \text{and } b = 8{\cdot}35.$$

$$\text{Hence winding dispersion } \sigma_1 = \frac{3}{N^2} = \frac{3}{13{\cdot}5^2} = {\cdot}0164$$

$$\text{peripheral} \quad ,, \quad \sigma_2 = \frac{\delta}{X N \tau} = \frac{{\cdot}05}{{\cdot}285 \times 13{\cdot}5 \times 13} = {\cdot}0010$$

$$\text{flank} \quad ,, \quad \sigma_3 = \frac{6\,\delta}{b} = \frac{6 \times {\cdot}05}{8{\cdot}35} = {\cdot}0360$$

$$\text{and} \quad \sigma = \sigma_1 + \sigma_2 \times \sigma_3 = {\cdot}0534$$

The mean experimental value for σ for the first motor was ·0625, so that the difference between calculation and observation is ·0071 or 14·6 per cent. of the latter. For the second machine the experimental value is ·058, the difference being ·0046, or about 8 per cent. of the experimental value. Time has not permitted us, however, to take such careful observations on the second motor, and there may be some small differences in the dimensions.

The difference between the experimental and calculated values of the dispersion is somewhat greater than one would like, but it is probably due to some extent to the very high magnetic saturation which appears to exist in the teeth of these machines. We have calculated the induction density in the core and teeth from the voltages and dimensions, and find that the core density is about 4,100 maxwells, while in the rotor teeth it is 13,000, and in the stator teeth no less than 17,200 maxwells in the narrowest part. This very high induction doubtless causes considerable leakage which would not be accounted for by Dr. Behn-Eschenburg's formula. It is, of course, only fair to say that an error of a little more than a tenth of a millimetre in the estimation of the gap would account for the discrepancy between the experimental and calculated results, but the measurements were most carefully taken, and I do not think that any great part of the discrepancy is due to errors of measurement.

In passing it may be mentioned that since nearly 70 per cent. of the total dispersion is due to the flanks, a considerable improvement might be effected by copper end plates to the core. It is, of course, hardly possible to try this on an already wound machine, but it would be interesting to know if Dr. Behn-Eschenburg has investigated this point.

Finally, Dr. Behn-Eschenburg's paper is of great value, in that it shows the importance to which the manufacture of polyphase motors has attained on the Continent, and it is to be hoped that we shall soon see a much larger output of these motors here. Their efficiency, simplicity, and freedom from commutator troubles, in my opinion, make polyphase superior to direct-current motors for nearly every purpose except traction. The only important objection to them is their poor speed regulation, but there are comparatively few instances where this is really a vital matter, and the new variable-speed motors should fill this gap.

Mr. Hobart. Mr. H. M. HOBART (*communicated*): The data contributed in Dr. Behn-Eschenburg's paper are of great value to those engaged in induction motor design. The exhaustive series of comparative tests which are described in the paper, throw more light on the subject than any contribution since the publication of Behrend's investigations. Dr. Thompson has mentioned Behrend's formula for the determination of σ. It reads, in its original form:

$$\sigma = \frac{\text{Constant (C)} \times \text{Radial depth of Air-gap } (\Delta)}{\text{Polar-pitch at Air-gap } (\tau)}$$

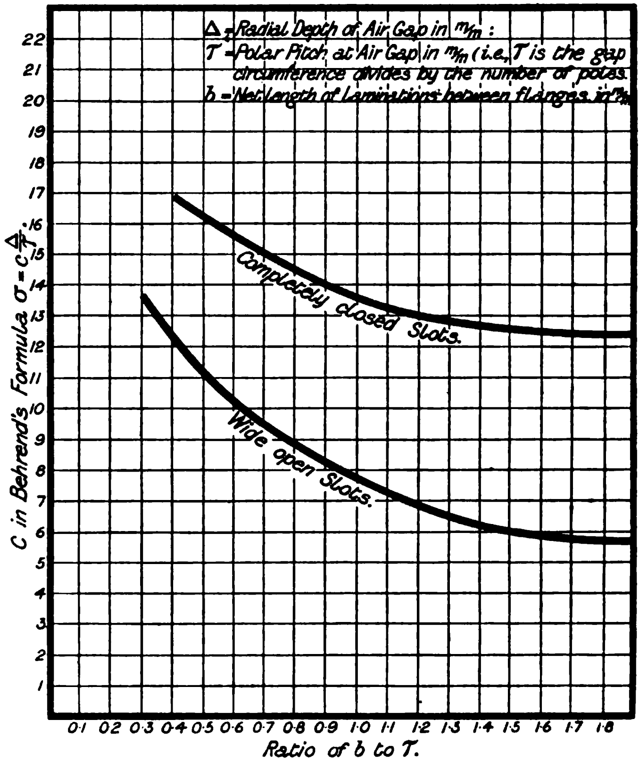


FIG. D.

This formula of Behrend's is in refreshing contrast with many which have been proposed, and it is satisfactory to note that Dr. Behn-Eschenburg's formula is also of fairly moderate length.

While reluctant to depart from the ideal simplicity of Behrend's formula, I have found it convenient to determine the constant C, from a set of curves which take approximate account of the ratio $\frac{b}{\tau}$, *i.e.*, of core breadth b, to polar-pitch at air-gap τ. This is necessary because

of the large percentage which the inductance of the end connections bears to the total inductance, and I am glad to find that Dr. Behn-Eschenburg's results confirm my view. My theory has been criticised, and it has been alleged that I considerably overestimated the inductance of the end connections. Although I have had ample proof of the correctness of my view, I realised that it was opposed to the recognised practice of employing large diameters and short lengths in induction motor design. Mr. Hobart.

My curves are reproduced in Fig. D. They first appeared in the *Elek. Zeit.* for 1903, Heft 46, p. 934. I have found that they give excellent results. Dr. Breslauer (*E. T. Z.* 1903, Heft 48, p. 987) first pointed out that the chief defect, namely, that they do not take into account the zig-zag dispersion along the heads of the teeth (discussed by Kapp and designated as "Zic-zack-strenung" in *Elektromechanische Konstruktionen*, 2 Auflage, 1902, p. 187). This zig-zag dispersion is almost negligible with many slots and moderately deep air-gaps, but with few slots and very short air-gaps it may rise to a very high figure. I am indebted to Dr. Behn-Eschenburg for the data contained in his paper regarding such machines. In order to compare the results obtained with his formula with those obtained by Behrend's method, I prepared Table I., for the 33 Oerlikon motors of which data is given in Dr. Behn-Eschenburg's paper. This data was so complete that but few assumptions were necessary. One of these was to take X = 0·1 wherever it was not given in the paper, and this, where wrong, could not appreciably affect the final conclusions. As the result of this comparison, I found that my method of using Behrend's formula gave an average disagreement of 15 per cent. from the observed results, whereas Dr. Behn-Eschenburg's formula, as given on page 268 of his paper, leads to an average disagreement of 23 per cent. I was, however, dissatisfied to find one case in which the observed result was practically twice that derived by Behrend's formula. A little examination showed that this motor had few teeth per pole and an exceedingly short air-gap.

Such proportions are highly undesirable from the practical standpoint, and the very short air-gaps lead to far less gain than is generally believed, for the reason that this zig-zag dispersion then becomes so considerable. Moreover, such short gaps are mechanically undesirable. Hence my method of using Behrend's formula gives a much closer average agreement when applied to practical cases of commercial motors. Nevertheless, it is interesting to examine into the improved accuracy obtainable by introducing into my method a correction for the zig-zag dispersion. This may be done by means of the curve in Fig. 2, in which the ordinates give values for an additional constant C^1 to be introduced for corresponding values of the abscissæ, which are equal to the product of depth of air-gap (Δ) and number of slots per pole (N), *i.e.*, to $\Delta \times N$.

Behrend's formula must now be written—

$$\sigma = C\, C^1 \frac{\Delta}{\tau}$$

Mr. Hobart. and C and C^1 must be determined from the curves of Figs. 1 and 2 respectively.

For the thirty-one examples for which the paper contained the observed values of σ, I have set forth in Table II. the value of b, τ, $\frac{b}{\tau}$, X, C, Δ, N, $\Delta \times$ N, C^1, σ as determined from Behrend's formula $\left(C\,C^1\frac{\Delta}{\tau}\right)$, the observed values of σ, and the percentage disagreement between the values thus estimated and the observed values. It will be

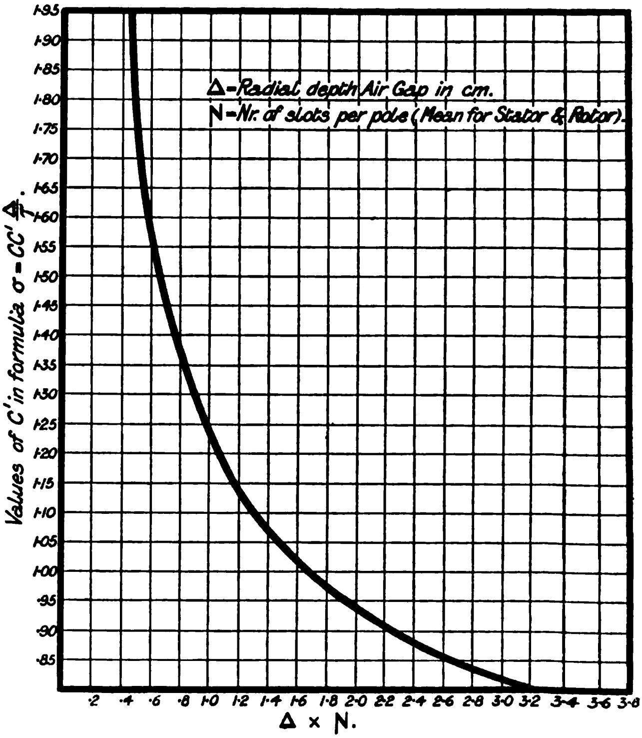


FIG. E.

seen that the average disagreement is but 9 per cent. This is a much more accurate average result than is obtained by Dr. Behn-Eschenburg's formula, and the method is, moreover, much more simple.

The range of satisfactory practical designs generally lies between values of 0·8 and 2·5 for $\Delta \times$ N, and for this range of values it may often, in rough calculations, be permissible to omit C^1 from Behrend's formula. With the tendency to employ lower periodicities, the values both for Δ and N will increase in the near future, and C^1 will often be less than unity, whereas the present tendency of Continental practice with very small air-gaps occasionally leads to values of C^1 as high as 2·0. It seems to me that this analysis should afford an additional

argument against the use of high values of τ and small values of Δ as means for obtaining high power-factors. Fig. D shows that high values of τ may lead to such increased inductance of end connections as to limit power-factor improvement in this direction, and Fig. E shows that when Δ is decreased beyond certain limits, the zig-zag dispersion increases so rapidly as to limit any power-factor improvement by this means. Mr. Hobart.

In these comparisons I have confined myself exclusively to the data given in Dr. Behn-Eschenburg's paper regarding the Oerlikon motors. The agreement between these data and the results obtained by my method of employing Behrend's formula is the more interesting from the fact that the curves of Fig. D were derived altogether without reference to Oerlikon motors, being largely the result of investigations on motors of quite different types.

It appears fairly certain that the use of Behrend's formula in its present form, namely—

$$\sigma = C\, C^1 \frac{\Delta}{\tau},$$

the constants C and C^1 being determined respectively from the curves of Figs. 1 and 2, will, for practically all commercial types of induction motors, yield very good results.

In applying Dr. Behn-Eschenburg's formula to his motors, I have taken the observed value of σ as the right one. Had I taken into consideration the fact that this σ was observed at standstill (Dr. Behn-Eschenburg quite rightly points out that the rotor should preferably be slowly revolving), and that lower values for σ would better represent the practical conditions, a considerably better agreement with the results from Dr. Behn-Eschenburg's formula would have been obtained.

I have done this in Table III. by following Dr. Behn-Eschenburg's suggestion to substitute the factor $2 \times \frac{3}{N^2}$ for the factor $\frac{3}{N^2}$. The observed result should then, according to Dr. Behn-Eschenburg, agree with the calculated result. It will be seen from Table III. (p. 288) that his method there shows an average agreement within 15 per cent. I am not, however, of the opinion that the difference between these two values is so great as Dr. Behn-Eschenburg assumes. From the available data he finds a value of

$$K_1 = 2{\cdot}5$$

for the most unfavourable position, and assumes therefore a value

$$K_1 = 1{\cdot}25$$

for the mean position. The following considerations seem to show that this assumption is unjustified. The so-called winding coefficient represents those lines which go from stator tooth A to rotor tooth B, and then to stator tooth C. The position shown in Fig. F is, of course, the most unfavourable position—*i.e.*, σ is a maximum in that position. If B is just opposite A there is no zigzag dispersion. If we denote

Mr. Hobart.

TABLE III.

No. of Motor.	Calculated.	Observed.	Disagreement. Per Cent.
1	·054	·06	10
2	·0727	·09	19
3	·0419	·045	7
4	·0606	·075	19
5	·0506	·050	1
6	·0703	·063	11·5
7	·0425	·042	1
8	·0622	·056	11
9	·0715	·067	7
10	·0515	·046	12
11	·0531	·054	1·5
12	·0589	·070	16
13	·0552	·060	8
14	·0545	·054	1
15	·0551	·062	11
16	·0419	—	—
17	.0508	—	—
18	·0555	·046	21
19	·0645	·055	17
20	·0634	·040	58
21	·0724	·054	33
22	·0356	·042	15
23	·0294	·022	33
24	·0611	·067	8·5
25	·0347	·0328	6
26	·0667	·064	4
27	·0333	·034	2
28	·0539	·060	10
29	·0343	·043	10
30	·0763	·054	41
31	·0355	·039	9
32	·1049	·075	40
33	·0790	·065	21

Average disagreement = 15 per cent.

by $2\sigma_1$ that part of σ representing the zigzag dispersion, then $2\sigma_1$ i a maximum in Fig. F and is in that position about twice as large as th average value.

If, therefore, Fig. F is repeated over the whole circumference—th is, if the number of stator slots is equal to the number of rotor slots— then no doubt the maximum zigzag dispersion $2\sigma_1$ is double the averag zigzag dispersion. But whenever the number of rotor slots is nc equal to the number of stator slots the value of the ratio $\frac{\text{maximum }(2\sigma_1}{\text{average }(2\sigma_1}$ must be considerably smaller than 2, as there are in every positio some stator teeth opposite rotor teeth and some stator teeth opposit rotor slot openings; in fact, there is never any position without zigza dispersion. The ratio should, therefore, in all practical cases be neare to 1 than to 2, but an exact value can only be found by experiment.

Mr. Hobart.

The fact, however, that there is a difference between σ as measured at standstill and as measured with the rotor slowly revolving cannot be denied, and is not only of theoretical interest, but of great practical importance.

Dr. Behn-Eschenburg's formula has one very great advantage over my method, namely, that from it one sees at a glance the relative values of the three dispersion fluxes, and this is of considerable help in designing.

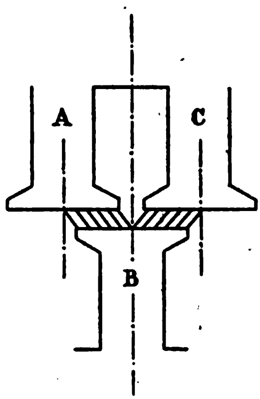


FIG. F.

The possibility which I have demonstrated in this analysis of obtaining an average agreement within 9 per cent. between theory and practice on these thirty-one motors reflects great credit upon the exactness of the workmanship in the Oerlikon factories, as also upon the intelligence and care with which the tests were made. Very different experiences in analysing the test results from many other companies leads me to the opinion that no other large electrical manufacturing company in the world is manufacturing and testing with such exactness.

Professor Thompson

Professor SILVANUS P. THOMPSON (*communicated*): On the occasion of presenting to the Institution the paper of Dr. Behn-Eschenburg, I endeavoured briefly to explain its salient features from the author's point of view. To these I now propose to add a few comments of my own.

The definition which Dr. Behn-Eschenburg gives of the *Dispersion-coefficient* σ differs slightly from that adopted by M. Blondel and others. Dr. Behn-Eschenburg takes as this coefficient the ratio of the no-load current to the short-circuit current (at equal voltages). Whereas Blondel's coefficient is equal to σ multiplied by the fraction $\frac{1}{1-\sigma}$; and hence is less than Behn-Eschenburg's by some 3 per cent. for large motors, or by some 8 or 9 per cent. for very small motors. If we denote the ratio of the short-circuit current to the no-load current as U, (having values varying from 11 or 12 in small motors to 30 to 40 or more in large ones), then Behn-Eschenburg's σ is the same thing as $\frac{1}{U}$, while Blondel's σ is $\frac{1}{U-1}$. This would make y, the ratio of the maximum torque to the torque which exists at maximum power-factor (or, in other words, the capacity for overload), to have the value $y = 0{\cdot}5\sqrt{U-1}$, or, approximately, $0{\cdot}5\sqrt{U}$. Blondel's σ expressed in terms of the coefficients of self and mutual induction will be $=\frac{L_1L_2-M^2}{M^2}$, while Behn-Eschenburg's $\sigma = \frac{L_1L_2-M^2}{L_1L_2}$.

It would be an obvious criticism upon the whole paper to suggest that if an effect can be expressed in terms of quantities that can be deduced from first principles, then it had better be so treated than by

Professor Thompson.

the aid of arbitrary coefficients which have to be obtained by comparison of experiments upon machines. But in the present instance the detailed phenomena of magnetic dispersion which govern the whole performance of the induction motor, and which make the entire difference, in modern designs, between a good motor and a bad one, are so complicated, that it is almost hopeless to attempt to deduce working rules from them; and, in fact, no such rules have been yet deduced. The relative importance to be attached to the various considerations involved in such deductions has been so far beyond knowledge that the deduction of working rules has been impracticable. What has been done by Kolben, Behrend, and others has been to state certain very simple empirical rules, of which Behrend's is perhaps the best. This rule assigns to σ the value $C \times \frac{\delta}{\tau}$; where δ is the length across the air-gap, τ the length of the pole-pitch at the face, and C a coefficient having values that usually lie between 10 and 15, if δ and τ are given in centimetre measure. Hobart has tried to improve the formula by assigning values to C depending on the ratio of pole-pitch to armature length, and finds values which for open slots lie between 6 and 13·5, and for totally closed slots lie between 12·5 and 17·7. But a formula which ignores the part played in the determination of magnetic dispersion by the axial length of the core and by the disposition of the projecting ends of the windings is so obviously imperfect, that it could only at the best be a rough guide. Between such an elementary rule and the precise rational expressions with all their complications that theory might dictate, there was certainly some middle course to be preferred. The task which Dr. Behn-Eschenburg has undertaken, and completed with no little skill, was first to apply theoretical considerations to dissect into its three principal component parts the sources of the magnetic dispersion, and to establish simple approximate formulæ for each separate part, while leaving in each part an empirical factor or coefficient the value of which could be deduced from the experience of the factory by experiments and calculations from actual machines. And so he has arrived at the result finally restated on p. 269, where in formula (9) the value of σ is given as the sum of three terms which are respectively contributed by the zigzag leakage, the peripheral leakage, and the flank leakage.

Upon this important formula, which is the main achievement of the investigation, and which will, I believe, prove of permanent importance to designers, there are two comments to be made. First, as stated, it is obviously applicable to machines with open or semi-open slots only, since X is the width of the slit at the top of the slot. It should be observed, however, that in the case of machines with closed slots Dr. Behn-Eschenburg has given on p. 249, equation (5A), an alternative expression (it needs to be multiplied by 2 when inserted) for insertion in equation (9) in the place of the second term, when closed slots are under consideration. But, further, he gives as the result of experience, on p. 263, the statement that for closed slots in which the iron bridge is made thin enough this term of the dispersion-coefficient may be estimated at about four times greater than for slots with slits.

The second comment on formula (9) is that the second term of it is not homogeneous with the others, and indeed needs amendment. As σ itself is a purely numerical ratio, each of the three terms of which it consists must also be a pure numeric devoid of dimensions. Now the second term, $\frac{\delta}{X \times N \times \tau}$, is not a pure numeric, since δ, X, and τ are each of them lengths. Hence it is clear that somewhere there is a suppressed dimension. Examination of the argument by which it was established shows that this suppression occurs on the first line on p. 249, where the edge-thickness of the overhanging top of the tooth is "set down tentatively for the usual forms of slots as 0·1 cm." This assumption runs through all the formulæ from that point. If the symbol e be adopted for this edge-thickness or depth of the tooth-top (equal to the thickness or depth of the iron bridge if it has not been cut away), then the expression on p. 249 for the reluctance of the air-space between the tops of two neighbouring teeth may be re-written— Professor Thompson.

$$\rho = \frac{X}{e \times b \times K_2};$$

and, carrying this through the other formulæ, we get as the second term in formula (9)—

$$\frac{10 \times \delta \times e}{X \times N \times \tau},$$

which is a mere ratio, and will be true whether the four lengths δ, e, X, and τ concerned are expressed in centimetres or in inches.

In the end of his paper, Dr. Behn-Eschenburg has introduced a most convenient device, in his tabulation of the formulæ for the performance of the motor at five different points of the load, viz. (1) no-load, (2) about half-load, (3) normal full-load, (4) about 1¼-load, (5) the maximum possible over-load. These formulæ are quite handy, and will save much time to calculators.

The specific loading of an armature or stator, or number of ampere-conductors per unit length of periphery, for which, on p. 275, the symbol JL_0 is used, is a quantity most vital in designing. The values given on p. 275 for this quantity are: 150 amperes per centimetre for motors of less than 10 H.P., and 250 amperes per centimetre for exceeding 100 H.P. Designers may be glad of a formula that will afford them a reasonable figure for all different powers. I have found a convenient one, which, for the present case may be written as—

$$JL_0 = 90\,(1 + \tfrac{3}{4} \log \text{H.P.}).$$

It is interesting to observe that equation (18), when the mean values are inserted, yields a dimension formula akin to that of Steinmetz, and which may be written—

$$Db = 17{\cdot}5 \times \text{KVA},$$

or in inch measures—

$$D''b'' = 2{\cdot}71 \times \text{KVA}.$$

As the constant, here inserted at a mean numerical value, varies

Professor Thompson.

inversely as the specific loading JL_o, it will be smaller for motors of large output, and conversely.

Mr. Cramp.

Mr. W. CRAMP (*communicated*): While admitting to the full the great intrinsic value of the results recorded in this paper, it seems to me a pity that more and more literature should be written on the subject of the Induction Motor without in the least attempting to bring the terminology into line with what we have all been accustomed to for so many years in the design of direct-current machinery. This is an especially good opportunity of calling attention to the curious lack of forethought on the part of those who are responsible for the present making of theory which future students will have to digest. For how shall a student connect Dr. Behn-Eschenburg's "σ" with Dr. Hopkinson's "coefficient of leakage" to which we are all accustomed, and which is so easily understood?

Nor is Dr. Behn-Eschenburg the only one who appears to err in this respect, for both Behrend and Heyland use a notation different from Dr. Hopkinson's, and in some cases different from each other's. This is not a *national* plea, for the "leakage coefficient" mentioned above is found to be adopted in the leading text-books of all languages.

The difference between it and "σ" is not great, which is another reason for "σ" not being allowed to creep into our text-books.

Dr. Behn-Eschenberg defines "leakage coefficient" as follows:—

$$\text{Leakage coefficient} = \sigma = \frac{J_o}{J_k} = \frac{\text{no-load current}}{\text{short-circuit current}},$$

which is also practically—

$$= \frac{\text{permeance of leakage paths}}{\text{permeance of the main magnetic circuit}}$$

Now Dr. Hopkinson's leakage coefficient, which, with Professor Thompson, we will call v,

$$= 1 + \frac{\text{permeance of leakage paths}}{\text{permeance of the main circuit}},$$
$$= 1 + \sigma,$$

and in the same way we may translate just as easily the condition of maximum power-factor into terms of this old coefficient v; and, indeed, the whole of the calculations for an Induction Motor may be thus carried out just as easily as with the new "coefficient" which appears to be gaining ground. By keeping to the old notation we gain an advantage most obvious to both students and teachers.

Mr. Paterson.

Mr. C. C. PATERSON (*communicated*): With reference to Dr. Drysdale's remarks on the experimental measurement of σ in asynchronous motors, it is true that when σ is large it may be quite as convenient, and almost as accurate, to measure the transformation ratios of stator to rotor, and rotor to stator. Dr. Behn-Eschenberg denotes these by $\frac{M_1}{L_1}$ and $\frac{M_2}{L_2}$, and deduces σ from the formula—

$$\sigma = 1 - \frac{M_1 M_2}{L_1 L_2},$$

where L_1 and L_2 are the coefficients of self-induction, and M_1 and M_2 those of mutual induction, although from the strict point of view these are not *mutual* coefficients.

Mr. Paterson.

For values of σ lower than 0·4, however, measurement by this method implies the observation of such small differences of voltage that an error of 0·1 per cent. in reading the instrument may produce an error of 3 or 4 per cent. in the value of σ. As in all motor tests, the values of the no-load and short-circuit currents must be known in order that the performance of the machine under load may be estimated, σ can be at once deduced by dividing one by the other, and the measurement of the transformation ratios is then only of use for determining the ratio between stator and rotor leakage.

It is sometimes urged that when σ is considered as the ratio between no-load and short-circuit current no allowance is made for the diminution of current due to stator and rotor copper-drop, and that whereas theory assumes that the power-factor of the short-circuit current is 0·0, in reality it is of the order of 0·3, making σ 5 per cent. greater than it really is. The fact is not always taken into account, however, that when the short-circuit current is measured the rotor is stationary, or nearly so, and the current in the rotor windings has the same frequency as that in the stator. Hence there are losses occurring due to eddy-currents in the heavy copper windings of the rotor, which do not exist when the machine is running; thus the short-circuit current appears greater than it should, which, to a large extent, counterbalances the error introduced by neglecting the effect of copper-drop in the windings. In this connection it is interesting to note the difference between the calculated C^2R losses for any motor at short-circuit and those actually measured with a wattmeter. The difference generally amounts to between 30 and 40 per cent.

Dr. Drysdale laid stress upon the danger of damaging the winding of a machine owing to the large currents flowing at short-circuit. It is quite permissible to increase the stator voltage until about twice the normal current circulates in the windings, and then increase the measured current in the ratio of normal voltage to that used in the test.

Dr. Behn-Eschenburg.

Dr. BEHN-ESCHENBURG (*in reply*): I desire to express my sincere thanks to all the gentlemen who have taken part in the discussion of my paper. With respect to the remarks of Mr. Hobart, I permit myself to say that the simplified formula which he mentions under the name of "Behrend's formula," was already previously used by me, and is for example to be found in the pamphlet of the Oerlikon Machine Co., *Sur le Calcul des Machines*, which was widely distributed at the Exhibition in Paris in June, 1900, wherein, on p. 26, it is deduced and described But since this formula leaves unconsidered certain very important conditions that are of great influence with respect to the magnetic dispersion, I sought for a more complete formula, and have now put forward the same in my present article as being a closer approximation to the truth. The new formula has therefore been developed precisely out of the old formula.

In conclusion, I desire to express to Professor Silvanus Thompson my thanks for the trouble he has taken in translating my paper.

The PRESIDENT announced that the scrutineers reported the following candidates to have been duly elected :—

Members.

Henry T. Davidge
John A. Rudd
William I. Taylor

Associate Members.

Charles Adams
Carl B. Auel
Philip C. Booty
Richard B. Burrowes
Richard C. Dieppe
Philip H. England
James J. Fyfe
John G. Griffin
Wilfred M. Harrop
Robert W. Hutchinson
Hugh H. F. Hyndman
Alexander D. Linzell
James McI. McBlain.
Anthony H. McBryde
Robert S. McLeod
Robert Meakin
Radley, Mott-Trille
Prof. John Orr, B.Sc.
George D. Poulton
Hal J. Robinson
Randolph P. G. Sims
Campbell Smart
Kennett R. N. Speir
John T. Taylor
Charles G. Trevett
William H. Turner
John C. Whiteley
Benjamin D. Williams

Associates.

Francis G. C. Baldwin
Oliver H. Bishop
Basanta C. Bonnarjee
John Carlaw
George H. Congdon
Richard B. H. Cragg
Kamel O. Ghaleb
Harry N. Howlett
James W. Jackson
Charles B. Johnson
Alexander H. Law
Robert Lindsay
Richard A. Parsons
Samuel C. Rhodes
Charles Richardson
Edward E. Robb
Douglas Sheppard
Herbert C. Siddeley

Students.

Arthur H. Acres
William B. Adams
Frederic Bacon
Thomas O. H. Bates
Henry P. Baynham
Douglas W. Belbin
Lawrence G. Bennet
Frank G. Brookes
John K. Catterson-Smith
George F. Cobham
Walter R. Cooper
Louis C. Cuffe
Edward R. d'Ade
Reginald M. Derry
Charles F. Edwin
Sydney Featherstone
Ernest H. Field
Frank Goodall
Alec. Hartley
Eric M. Hayward
Hallowell Headley
Charles H. Hitchen
George Holliday
Ernest P. Hollis
Stratten Holmes
Gerald Jacques
M. Jennison
William C. C. Langdon
Charles E. Lucas
Thomas J. Sack
Rustam M. Sethna
Addison B. Smith
Arthur C. Stacey
William G. Turner
Thomas A. Vincent
Sydney E. Weeden

GLASGOW LOCAL SECTION.

INAUGURAL ADDRESS OF THE CHAIRMAN,

W. A. CHAMEN, Member.

(*ABSTRACT.*)

(*Address delivered November* 10, 1903.)

The Chairman, after thanking the Local Section for the honour they had conferred upon him, proceeded to review the position of the Section, showing that while in October, 1900, they had 104 members, in October, 1903, the membership was 198. He drew attention to the fact that the Electrical Industry was increasing in extent in and around Glasgow, and stated that the number of members would probably still further considerably increase. He reminded members of the object of Local Sections, and pointed out the advantages they present as compared with isolated independent Institutions in various parts of the country. He also stated that the fact that papers presented to Local Sections could not always be printed in the Journal of Proceedings should not deter members of Local Sections from giving papers, and was not in any way to be taken as an indication that their papers were not of great value locally.

The Chairman proceeded to take a general survey of the position of the Electrical Industry around Glasgow at the present time, dealing specially with the advance made in the use of steam turbines, and pointing out that this sudden advance had apparently followed the adoption of steam turbines in fairly large sizes for the propulsion of steam ships on the Clyde. The great advantage the steam turbine possessed in its application to electricity undertakings was its low first cost, which would be bound to tell upon the standing charges,—which form such a serious item in electric lighting undertakings suffering from heavy peak loads,—even if the steam consumption were to prove slightly higher than with steam engines, though he did not think this this would be the case.

The question of the large gas engine for electricity supply undertakings was touched upon, but the Chairman dismissed it from serious consideration at the present time, on account of its heavy first cost and the large amount of space required, again pointing out that in cases where the coal consumed cost about ¼d. per unit of electricity supplied, out of a total average cost of 2·94 pence, the saving of a fraction of this farthing might be of no use whatever if it was effected at the cost of considerably increased capital expenditure.

The use of superheated steam was briefly touched upon, and the the statement was made that on the whole the outlook for the further cheapening of the production of electricity at the present time is decidedly hopeful.

The question of distribution was next dealt with, and it was pointed out that no move had been made in this direction except by the introduction of very high pressure for transmission purposes. Every one seemed to take it for granted that there was no possibility of conducting electricity in any cheaper manner than by means of pure copper conductors. The possibility of transmission without conductors at all was sometimes spoken of by sanguine people, but in such a case the Chairman did not see where the meters would be fixed.

The question of supply and demand was referred to, and the old bone of contention about different systems of charging was mentioned.

The development of electric tramways was referred to, and the effect they might produce upon rural districts was briefly considered. The electrification of railways was also indicated as an essential step for City and Suburban local traffic in the immediate future. The possibility of the development of electrical power supplies over large districts of country was referred to, and its probable effect in the way of assisting the spread of industry away from cities and the consequent improvement of the general health of the community was suggested. Reference was made to the possibility of running electric motor-cars in a country ramified in all directions by electricity supply mains, where no difficulty would arise about charging the accumulators at any place.

With regard to electric lighting, the Nernst lamp with its possible improvements, the flame arc lamp, and the Cooper-Hewitt mercury vapour lamp were indicated as possible sources, after due development, of further economies in the cost of production of light.

The address concluded with a reference to the telephone and telegraph industries, and an expression of the hope that those of their members who belonged to either of these branches of the electrical profession would continue to take a warm interest in the doings of the Local Section. Any papers with regard to either of these industries which might be brought before the Local Section would be received with pleasure and listened to with interest.

DUBLIN LOCAL SECTION.

INAUGURAL ADDRESS OF CHAIRMAN,

Professor W. E. THRIFT, Member.

(*ABSTRACT.*)

(*Address delivered November* 12, 1903.)

After thanking the Section for the honour conferred upon him by his election as their Chairman for the ensuing year, the Chairman proceeded to give a general *resumé* of recent electrical progress. He alluded especially to improvements made in connection with electric lighting; motors and generators, as well as to steam turbines, gas engines, and vapour pressure engines. In the domain of pure science he referred to M. Blondlot's newly-discovered N-rays, the varied usefulness of the Cooper-Hewitt mercury lamp, in particular to the possibility of obtaining by means of it a train of waves of definite character and frequency, and to recent researches on radio-active bodies. After detailing the earlier discoveries with regard to these bodies, the Chairman proceeded :—

A step of fundamental importance was the separation from Thorium and Uranium, by chemical means, of constituents, called Th X and Ur X, by Rutherford and Soddy, and Crookes respectively, which removed from Thorium and Uranium their power of emitting β-rays though they retained the power of emitting α-rays. Th X gives out α- and β-rays and a radio-active emanation, while the radiation from Ur X consists mainly of β-rays. The energy emitted in α-rays is much greater than that in β-rays. While Th X and Ur X decay in their powers, the Thorium and Uranium from which they have been separated recover their original power at precisely the same rate, so that the sum total of the activity of the two constituents remains constant.

Investigation of the radio-activity excited in other bodies by Radium and Thorium showed that it is due to the deposit of radio-active matter, transmitted by positive carriers produced from the emanations, perhaps by the expulsion of negative bodies from its molecules, for in that it emits β-rays we have evidence of such expulsion occurring. Information as to the character of the α-rays was soon forthcoming. The rapid increase of their absorption with the thickness of the matter traversed pointed to their being projected particles, and Rutherford and Becquerel proved that they are deviated by a magnetic field in the opposite direction to the deviation of the β-rays, but to a smaller extent, according with an estimate of the mass of the particles as of the order of the mass of the H atom (about twice as great) and of their velocity as equal to one-tenth of the velocity of light.

Examination of the emanations showed that they behave like inert

gases, diffusing through gases like gases of considerable molecular weight. The activity of radium is largely due to its emanation and the excited radio-activity caused by it, the activity of fresh emanation increasing for a time because the excited radio-active matter manufactures out of itself the fresh active matter which causes the excited radio-activity. The emanation is continually being produced, and is occluded like a gas in solid radium compounds, a sudden evolution of the emanation resulting when the solid is dissolved. The radio-activity of fresh radium therefore gradually increases with increase in the amount of occluded emanation; and with the loss of the occluded emanation, when it is dissolved, it retains the excited radio-activity, and therefore its activity at first diminishes and then increases to its normal maximum. The emanation gives out α-rays at first, β-rays afterwards from the excited radio-activity. The emanations can be condensed by liquid air, regaining the gaseous condition on rise of temperature; they volatilise at fairly definite temperatures, that from radium at about -150° C., and that from Thorium at about -120° C.; and they appear to exert a real vapour pressure. So the excited radio-activity due to Thorium is volatilised at a definite high temperature and re-deposited on neighbouring bodies.

Besides having the power of emitting α- and β-rays and a gaseous emanation, radium was found to emit a third kind of rays not deflected by a magnet and of an exceedingly penetrating nature.

M. Curie found that it possessed the power of maintaining itself constantly at a higher temperature than its surroundings, and to an extent involving the continual emission from 1 gr. of radium of approximately 100 calories per hour, and Dewar proved that this power was (if anything) increased rather than diminished at the temperature of liquid hydrogen.

The excess of temperature of freshly prepared radium is not so great as in that which has been some time prepared, but it gradually rises to its maximum in about a month, appearing in this way to be intimately connected with the gradual occlusion of the emanation, and with the destruction of the emanation as its cause. This, along with the fact that Helium is generally found in the mineral sources of radio-active bodies and Rutherford's measurement of the mass of the "α" particles as equal to that of the Helium atom, as contrasted with the mass of the "β" particles approximately the same as that of the corpuscles in the cathode-rays as determined by J. J. Thomson, drew attention, if indeed additional impulse were necessary, to the products of the disintegration of the emanation. Ramsay and Soddy investigated its spectrum, found it of a new type, and non-permanent in character; after standing for four days the characteristic lines of Helium appeared, along with certain new lines, and Rutherford's suggestion that Helium might be one of the ultimate products of the disintegration seems to have been thus triumphantly verified.

We cannot fail to be struck by the ease with which the disintegration theory (to which reference had previously been made) co-ordinates and accounts for all the effects, produced by the radio-active bodies, that have hitherto been observed. To recapitulate, the theory supposes

that the atom of a radio-active body is in an unstable state, or rather that certain of its atoms are continually becoming unstable; whether from internal processes, such as that suggested by Lodge in that, on the electron theory, the atom must be radiating, because of the radial acceleration of the revolving charge, and, therefore, the charge must be approaching the centre of the atom and its velocity be ultimately increasing, until when it approaches the velocity of light an unstable state of things must ensue (though, on this theory alone, apparently one might expect all the atoms to become unstable together and an explosion ultimately to occur: perhaps, indeed, all substances are thus doomed to destruction or resolution into the primordial electrons); or whether, amid the vicissitudes of a varied career, from collisions with their fellows occurring at times, in such a way as to increase the velocities of some of the atoms beyond the ordinary limits at which their state is stable, or whether from a concurrence of both causes or whether in some way not yet understood, somehow or other the state of instability is reached. The unstable atom disintegrates with the ejection of at least one positively charged particle of the mass of the Helium atom; the residue, itself unstable, breaks up further, and as the decomposition proceeds, now with the emission of an α ray, now with that of a β ray, the negative electron, now with that of a γ ray, without electric charge so far as external bodies are concerned, and small enough to find its way through the internal avenues of other bodies with small risk of being obstructed, because not attracted by the matter of which those bodies are composed, until the last product of decomposition is reached, a stable product, and therefore one never to be detected by the methods specially applicable to radio-active bodies, because radio-activity is a mark of unstability. Thus arise at different stages in the process, Th X, Ur X, the emanations, the excited ratio-activities; thus the various radiations occur simultaneously with the coming into being of the new products; thus are explained the rise in activity with its age of newly-prepared radium up to a maximum when the gain in activity due to the secondary fresh products is counterbalanced by the loss due to the decay of those products; thus the initial fall in activity of radium from which the occluded emanation has been removed, followed by a rise as before due to the occlusion of fresh emanation; thus the general law that the proportionate amount of radio-active matter that changes in unit time is constant for each substance; and thus the thousand and one details that have so far been brought to light. Even the fact that the radio-active bodies are all bodies of the highest known atomic weight is perhaps accounted for, since it is likely that any arrangement of electrons forming an atom will be less stable the more electrons it contains. The evidence in favour of the view that the changes that occur are changes in the atom is very strong. They are independent of the state of chemical combination in which the radio-active body finds itself; they are independent both in character and velocity, of temperature within the wide limits of observation; physically and chemically they are beyond our power either to cause them or prevent them. (Our very notions of what is meant by chemical change would have to be altered so as to bring

them within its sphere.) They take place with the evolution of energy of quite a different order of magnitude from the energy set free in any known chemical change. The kinetic energy of the particles emitted in the α rays during the breaking up of 1 gram of radium, calculable from the measured mass and velocity of the particles, is, at the lowest estimate, as great as the energy set free in the chemical union of the hydrogen and oxygen required to produce 25,000 grams of water, perhaps 100 times as great; and weight for weight no other known chemical reaction liberates more energy than this. The energy continually being used by 1 gram of radium in ionising the surrounding air would suffice to boil 150 grams of water a year, while the heat continually being emitted by 1 gram of radium would boil 1 gram of water in an hour. Indeed any attempt to regard the changes causing radio-activity as chemical changes appears to me as likely to involve more revolutionary changes in accepted chemical doctrines than the recognition that chemical laws, the atomic theory itself, apply to reactions between atoms and atoms, limit our powers of dealing with matter, hedge the atom round with a screen impenetrable to our weapons of attack, but are themselves limited, in that they only apply to the more stable products towards which all atoms are inevitably tending of their own inherent nature, or perhaps in that they are only approximations, generally very close approximations, to the truth because nearly all the atoms of a special kind are stable, and it is only a comparatively rare occurrence for one of the 10^{20}, or so, atoms of which 1 c.c. of matter consists to be perturbed beyond its limits of stability. In this way I regard the new theory as an extension of the atomic theory; as confirming it rather than throwing doubt on it; for instance, it shows that the internal energy of the atom is extremely great, and so far explains our inability to do anything which may break up into its constituent parts an entity in which the connecting ties are of such enormous strength. In passing I cannot refrain from remarking on the extraordinary sensitiveness of the new method of investigation in comparison with even the most refined methods of chemical investigation. Rutherford has shown that 1 gram of uranium emits something like 2,000 α particles a second, and as the α radiation from a milligram is probably within the limits of observation, it follows that the emission of 2 α particles a second can be detected and that we are actually within range of observing the effects of the disintegration of a single atom of Uranium. The chemical balance might weigh 10^{14} atoms of Uranium.

It is easy to account on the theory for the continuous emission of heat from radium; in fact one might almost expect it to occur to a much greater degree. The α particles are easily absorbed by solid bodies, and therefore most of those projected from atoms not near the surface of the radium will be stopped by collisions with the internal atoms, and therefore a considerable development of heat will ensue.

Sufficient data indeed seem to be available to enable us to estimate at any rate the maximum amount of heat which could be thus developed. Rutherford has shown that the α radiation emitted probably comes from a layer not more than 0·0001 c.m. in thickness. If we suppose

1 gram of radium in the form of a sphere, the radius of the sphere would be about 0·3 c.m., and therefore the area of its surface would be about 1·1 square c.m., and the quantity of radium which succeeds in emitting the α rays would be about $\frac{1}{1000}$th gram, or all but the $\frac{1}{1000}$th part of the α radiation of the 1 gram of radium is absorbed in the radium itself. Now the energy actually emitted externally in the α rays from 1 gram is 2×10^4 ergs per second, and therefore the energy of the whole α radiation of the gram is 2×10^7 ergs per second, or 72×10^9 ergs per hour, equivalent to 1,800 calories per hour. Thus if the whole of the energy of α rays were converted into heat by impact within the mass, it might account for the development of eighteen times as much heat as that actually observed. This would appear, therefore, to be an adequate cause of the phenomenon. This estimate only gives a major limit to the amount, because the thickness 0·0001 c.m. of the externally active layer may be only a very approximate estimate, and also because it is very likely that many of the α particles within the mass, instead of having their energy converted into heat by impact within the mass, simply fill up the gaps in atoms which have lost an α particle, and so restore certain of the disintegrated atoms to their original state.

We naturally ask how long can such evolution of energy continue, and calculation sets a limit of a few thousand years to the "life" of radium. It has been thought that this raises a difficulty, for if its life is so short it should long ago have lost its powers in being resolved into the products of its disintegration. However, it is possible that the radiation and disintegration occur at different rates when it is in its mineral sources, owing to the extreme tenuity of its distribution throughout their mass, and even without resorting to this assumption, which may not be in accord with the theory that the disintegration is atomic and independent of physical conditions, particularly if the instability of the atom arises from internal causes, there is the possibility, or probability, that radium is itself a product of the disintegration of another radio-active body, perhaps in existence or perhaps disintegrated some thousands of years ago. No Radium X has yet been discovered, perhaps because what we call radium is really the R X of the original radium.

The Chairman also referred to the electron theory, showed how the discovery of radium made it possible to put to the test of experiment the hypothesis that the mass of the atoms is due to the electrical inertia of electrons, and explained how, on the theories of Thomson and Abraham, this hypothesis is confirmed by Kaufmann's experiments.

In conclusion he said: The discovery of radium and its properties gives rise to many other speculations of extreme interest. It suggests a new source for the energy of the sun, and widely extends the previously estimated limits for the ages of the sun and earth, thus affording a new way of harmonising geological and physical theories. The emission of electrons from the sun may explain the electrification of the earth, the Aurora Borealis, the connection between magnetic storms and sun-spots, the photosphere and the corona. On similar lines may come the explanation of comet tails and their repulsion by

the sun, and of the nebular light. Radium may have the power of exciting luminous vibrations in the atoms of matter (when its emanation is mixed with air the spectrum of N has been observed), and it may give us information as to how those vibrations may be directly excited. In radium there may be found the long sought-for cures for cancer and consumption; it certainly appears to have a beneficial effect when used in the treatment of certain forms of external cancer. We are but on the threshold of discovery as to its applications to practice and theory. So the electron theory is little more than in the initial stage of its mathematical development: it opens up fresh avenues for research, and offers problems to the mathematician to solve of almost infinite variety and complexity, whether with regard to its own nature and properties, the explanation of gravitation and the proportionality of mass and weight, or in reference to the part which it plays in the structure of the atom. Surely there is no need to fear that in its unification of matter and electricity it may beget any unphilosophic contentment, rather will it spur experimentalist and theorist alike to fresh efforts to climb further up the hill of knowledge, whose peak is hidden in the clouds of heaven, and on whose lower slopes men yet are struggling.

NEWCASTLE LOCAL SECTION.

INAUGURAL ADDRESS OF THE CHAIRMAN,

G. GERALD STONEY, Member.

(*ABSTRACT.*)

(*Address delivered November* 16, 1903.)

This branch of the Institution of Electrical Engineers has now been in existence for four years, and the membership has risen steadily from 93 at the time of its inauguration to 152 at the present time.

One subject in which great interest is being taken, and which has produced as diverse opinions as has the problem of the proper way to mix concrete, or the best system of electrical distribution, is the education of engineers. On one thing, however, all are practically unanimous—that it is necessary to combine practice with theory; but everybody has his own special recipe for producing this mixture so that it shall be most effective. If a man, after leaving school, enters college and there completes his theoretical training, he is, as a rule, too old to do well in the shops, partly because a man of 21 or 22 is apt to object to being put next to boys of 16 to learn how to file and chip, and partly from having an inordinate opinion of the value of theory, which gives him often that very fatal disease well named by the Americans "swelled head." Similarly too, if after leaving school he spends some three years in the shops, he forgets most of what he has learnt at school, and no longer has that facility of mental application which is so useful to him in college. The fact seems to be that both practical and theoretical training should be carried on, as far as possible, concurrently, and this can only be done in practice by what is known as the "sandwich" system of alternate spells in the shops and in college. And now a word may be said as to the value of letting a boy in his schooldays learn the use of tools. Most boys with a mechanical turn of mind—and without this they will rarely become good engineers—will, with a little encouragement, spend a part of their spare time in any odd room or shed fitted up as a workshop, and there learn to hammer their fingers. An elaborate or expensive workshop is not necessary or even advisable. A strong table, with a vice, and perhaps an old foot-lathe, with a few joiner's tools, files, and soldering materials, are all quite enough to enable him to amuse himself; and in this way he will receive a training which, I believe, can be imparted in no other way, and which will prove of great value to him in after life, even if he eventually does not become an engineer.

And now may a plea be put in for the teaching of modern languages to engineers, instead of ancient. When one goes to Continental works it is rare to find a principal who cannot read English and, as a

rule, speak it also. What is the case in English shops? It is equally rare to find one who can either read or speak French or German. Thus a Continental engineer has full access to all that is written in either French, German, or English, and probably Italian also, while the Englishman is confined to English only. German is of especial value to electrical engineers, as such a vast quantity of work has been done in that line there. Now could not French and German be substituted for Latin and Greek in schools with great benefit? Of what use are Latin and Greek to an engineer except for their educational value, and is not the German grammar as good a training for the mind as Latin, besides the advantage that the boy can be taught how to learn a spoken language as well as a written one? Latin and Greek, as they are taught, only teach the learning of a language from the written point of view, and not from the oral, and to learn to speak and understand a spoken language is of great educational importance. Four foreign languages are too many for the average boy to learn; two are quite enough, and why should not these be French and German, which he will naturally keep up all his life, instead of Latin and Greek, in which he never opens a book the instant he passes his last examination.

Mathematics also should be taught from a practical point of view, so as to enable the student to make use of them in the actual problems which occur in practice.

In thus, however, urging a practical education for an engineer, no one more than an engineer is aware how much is owing to those who pursue science for itself, apart from mere monetary gain. Without the investigations of the immortal Faraday—out of which he deliberately refused to make any monetary gain—where would the whole of our modern electrical engineering be? Without the investigations of Faraday, Maxwell, Herz, Fitzgerald, Lodge, and many others, Marconi could not have made wireless telegraphy the brilliant success it has been. In almost all cases the way has been paved for the engineer and the commercial man by seekers after knowledge, which they have given to the world freely and without stint; and it is hard to say what bearing investigations in pure science may have in the future. Such discoveries as the fixation of atmospheric nitrogen, and thus the formation of nitrogenous manures, may be of great importance to agriculture, and the formation by electrolysis of many of the organic compounds found in plants may eventually give us a clue to the mystery of life, which, along with gravitation, is one of the great mysteries of Nature still to be solved by man.

The distribution of electricity for power, lighting, and traction has made enormous advances, and there is no sign of this rate of progress slackening. In this district we have the first of the great power-stations at Neptune Bank, Wallsend-on-Tyne, and soon a second one at Carville will be at work. During the past fifteen years the sizes of engines and dynamos used has steadily risen from about 100 kilowatts to from 4,000 to 5,000 kilowatts at the present time. In this connection the Parsons Steam Turbine has taken a notable part. This was invented by the Hon. C. A. Parsons, F.R.S., in 1884, and the first engine was about 10 horse-power, while now turbines up to 8,000 and 10,000 horse-power are

being made. The low first-cost, small steam consumption, absence of reciprocating parts, and small foundations, as well as reduced attendance and upkeep, have made this type of engine largely adopted for driving dynamos and alternators, as well as for the propulsion of ships and other purposes.

A great field has been opened up of late years by the researches of Crookes and others on Kathode and other similar rays, where we seem to be dealing with individual electrons instead of with great masses of them. These investigations led up to the discovery of the Roentgen rays, which, at first of only scientific interest, have proved to be of enormous practical value in surgery—another example of the practical application of scientific discoveries. Now recently we have had sprung upon us the marvellous properties of Radium, which not only gives forth three distinct kinds of rays, but also is warmer than the objects surrounding it, and is therefore constantly pouring forth energy. What is the exact source of this energy is still a disputed point, but may not these researches in molecular physics some day enable us to deal with individual molecules and not with masses of them, and thus tap the enormous source of energy that there is in the air surrounding us by the help of the "Sorting Demon" pictured by Clerk Maxwell. The second law of Thermo-Dynamics is true for masses of molecules only, and it may be possible that in the future we may find some way of harnessing the quick moving molecules of the air and let the slow moving ones go by. If we found out some such apparatus, we should be able to utilise for the service of man the energy of the atmosphere without the consumption of coal or other fuel. And if we look back on the advance made in the last hundred years, who will say it is impossible? Fancy our great-grandparents in the "Flying Scotchman" travelling at sixty miles an hour! What would they think when a telephone was put to their ears, or a gramaphone set going? What would the effect be on a stage coach if it met a bicyle or a motor car? Some of these things would have been declared impossible even within the memory of many of those present.

MANCHESTER LOCAL SECTION.

INAUGURAL ADDRESS OF THE CHAIRMAN,

EDW. W. COWAN, Member.

(ABSTRACT.)

(Address delivered November 17, 1903.)

After reference to some matters of local interest, the address deals with "Some Hindrances to the Development of the Electrical Manufacturing Industry in this Country." It is contended in the first place that the Electrical Manufacturing Industry is not in a healthy condition, and the small return made upon the ordinary share capital of companies manufacturing only electric light and power apparatus is instanced, nearly half of it bearing no interest at all. Among the reasons accounting for this condition of affairs, the general bad trade is mentioned which could be traced to the cost of the late war in South Africa. "A number of people speak as if the expenditure, giving as it did employment to so many workers, was a source of compensating profit to the country. These people do not grasp the nature of capital or realise that, as all free capital is passing through a process of rapid consumption and reproduction, if you consume without reproducing, all that capital is lost, and can only be replaced by *fresh savings.* The bulk of the free capital of the world is probably consumed every year, and the bulk of it reproduced in the same time. In so far, therefore, as this capital has been consumed unproductively, the country has lost that amount from its trade, and a large amount having been borrowed from other countries the burden is still on our shoulders. We may expect to find that our exports will increase relatively to our imports for some time to come, as a measure of the interest on this borrowed foreign capital."

Discussing next the statement so often repeated that "Municipal Contracts are not worth having," Mr. Cowan says :—

"My own opinion is that, allowing for certain contributory faults on the manufacturer's part, the essence of the unprofitable nature of these contracts lies in the introduction of an element of *risk or chance* without the corresponding chance of increased remuneration which should accompany all contracts in which there is the element of a gambling risk.

"This element of risk comes into these contracts under many headings. There is first the wording of the specification, and of the general conditions, which declare on the face of them a one-sided bargain. The manufacturer is called upon to sign, and does sign under the pressure of circumstances, a number of contracts containing clauses such as the following :—'The decision of the engineer shall be final

and conclusive as to the manner of carrying out the works, the quality of material and workmanship and the meaning of any clause matter or thing in the specification or of any of the plans, sections or drawings.'

"Such clauses it is true, may not and will not be acted upon by a fair-minded engineer, but they are there, and being there constitute a risk which has its value in pounds, shillings and pence, and whatever that value may be, it is not obtainable at the present time."

Other explanations of the unprofitable nature of these contracts are traced to the following causes:—

1. Delayed payments according to the terms of the contract, involving a lock-up of capital at a time when it is difficult to get capital.

2. The failure on the part of municipalities to pay promptly.

3. The delay in the issue of certificates for large amounts in order to stimulate promptness in getting trifling matters attended to.

4. The difficulty in standardisation owing to the unreasonable alterations required by many resident and consulting engineers.

5. The partiality of many resident engineers and consulting engineers to decide all matters of dispute against the contractor.

6. The high standard of perfection required under most difficult conditions, no reasonable allowance being made when conditions have arisen which the contractor could not possibly have foreseen when he tendered.

7. The desire of some resident engineers to put the contractor to unnecessary expense in the case of any defect requiring to be made good.

8. The ignorance of many resident engineers of the principles of business owing to their having been selected only on account of their technical qualifications.

9. The unsatisfactory but common arrangement in which the consulting engineers refer to the resident engineers questions relating to the carrying out of the contract, which results in the contractor having two masters to satisfy, one of whom has often had nothing to do with the specification and disagrees with it and everything in connection with it.

10. The impossibility of obtaining higher prices in order to cover the risks referred to on account of foreign competition, the foreign competitor often receiving greater indulgence than the home contractor, especially in respect to the acceptance of his designs without alterations.

Before passing to the second part of his address Mr. Cowan appealed to consulting engineers (or resident engineers when they act in a consulting capacity) to protect the manufacturers' interests as well as those of their clients.

"The consulting engineers could, in my opinion, have done much that they have not done in preventing municipal contracts from being brought into discredit. Let them see that the obligations on both sides are defined exactly and rigorously carried out. Let them make it their business to work for the elimination of one-sided agreements in respect to contracts, and let them combine leniency with strictness in just

proportion in controlling the execution of the work, and they will render a great service to the industry in this country. It is a primary condition of prosperity that the producers should be treated with justice."

FOREIGN COMPETITION.

Under the above heading the address deals at some length with the Fiscal question as it affects the electrical industry in particular. The importance of a knowledge of the elementary principles of economic science is emphasised as being necessary in order to give just consideration to the subject. It is shown that economic science only points out the road of ultimate highest economy, and that questions relating to our closer union with the Colonies, food supply in time of war, etc., must be considered quite apart from the merits or demerits of the adoption of a protective tariff as affecting commerce.

By way of introduction, the question of the relation between the value of exports and imports is discussed, and is shown to be normally that of an equation. The manner in which the shortage or surplus of specie in circulation and the banks acts automatically in keeping the connection between imports and exports an almost rigid one is explained. Every country must of necessity keep sufficient specie for its trade requirements, and the rates of exchange on foreign bills control that with such exactness that specie may be compared to water covering a large area the normal level of which is represented by the requirements of each part of it. Any departure from the normal level is quickly corrected by a flow from or to other parts.

Taking the above facts as a basis, conclusions are arrived at upon various problems connected with the effect of foreign competition upon home production.

The idea of Protection in the popular sense is to hedge in home trade by imposing tariffs on competing manufactures imported from abroad. The effect of a tariff is to narrow the field of competition, and it enables the home producer to obtain a better price. The consumer thus suffers; the Free Traders put it that the consumer is taxed for the benefit of the producers, or, in other words, that he subsidises the producer; and there is no escape from this view, though the consumer may not be taxed to the full extent of the tariff. The imports are, on account of the tariff, checked, and consequently also the corresponding exports. There is necessarily an economic sacrifice to the country, which no one would propose should be incurred unless there was some prospective advantage to be gained. The *raison d'être* of international trade for us is to exchange commodities which we can make cheaper or better than the foreigner, for commodities which he can make cheaper or better than we can. There is a gain to both sides. The more of this kind of exchange we have, the better for both countries.

Analysing the possible explanations of the demand for protection which are not based upon a fallacy, a hypothetical case is quoted in which the home consumers buy only imports to supply their needs:—

"What will then be the position of the home producers? They will not be idle, as some seem to think; they will be engaged in making exports of equal value to the imports. Of *equal value*, but not

necessarily at *equal profit.* They are in the position of a shop, the goods in which must be sold by a certain date, and they will have to sell them at what they can get for them, making up in quantity what is lacking in value. The problem is, of course, different under real conditions, but it appears to me that, at a time when demand for our exports is weak, it is in the nature of a *percentage difference* rather than neutralising one. When the demand is strong the case is altogether different, and I can conceive that in times when there is a large demand for our exports the placing of orders abroad will add to our prosperity. The more the better."

On the subject of transferability of labour the address quotes the fact that this principle is accepted in respect to *labour-saving machinery,* and contends that, that being the case, it is illogical not to accept the principle when applied to *labour-saving importation.*

Having distinguished between Scientific Protection and Popular Protection, it is contended that the former fails not in principle but in the difficulty in putting it into practice. The conditions under which a protection tariff would be justified are referred to at some length. The conclusions arrived at being summarised as follows :—

1. That Protection may be desirable, though economically unsound.

2. That Retaliation causes injury to our foreign trade, and results in economic loss unless effective in lowering foreign tariffs.

3. That temporary dumping for the purpose of destroying a home industry should be summarily dealt with.

4. That, in case of steady importation at prices below cost price of any commodity, the home producer must adapt or change his trade.

5. That intermittent dumping is detrimental to the development of our own manufacturing industry, and should be checked or stopped.

6. That placing orders abroad does not in times of normal trade involve loss of money to the country, loss of wages to the workman, or loss of profit to the home producers.

7. That when the demand for our exports is weak, loss may occur to the home producer when orders are placed abroad.

8. That the imposition of tariffs causes a check to the import and export trade, and that the consumer suffers loss.

9. That if our country is freely importing commodities from countries where the standard of well-being of the people is below that of our own, it may result in the dragging down of our standard nearer to that of the foreign country.

10. That if the people in this country are out-distanced by the people abroad, owing to their increased facilities for cheap production, or by high tariffs weakening the demand for our exports to an extent which rendered exportation with advantage impossible, protective tariffs will become a necessity.

There are many assumptions in the above conclusions, and some of these may not be justified by facts.

After a warning that the adoption of protection tariffs must involve economic sacrifice to the country adopting them as a *primary* result of their operation, the legitimate objects which might justify the sacrifice are summed up as follows :—

(1) The maintaining, as far as is consistent with the other principles enumerated, the natural and free course of international trade, so that all exchange, with a balance in favour of this country, shall continue unchecked.

(2) The protection of home industries when foreign competition results in such a depreciation of prices as to put an injurious strain upon the home producer in providing the corresponding exports.

(3) The protecting the standard of well-being of the people of this country from being dragged down to that of another country employing much low-paid labour.

(4) The mitigation of the suffering consequent upon the unrestricted working of individual self-interest.

(5) The fostering of new industries well adapted to the resources of this country until they have had time to develop sufficiently to hold their own without assistance.

(6) The checking of intermittent dumping, and stopping dumping which has been resorted to with the specific object of destroying an industry.

(7) The consolidation of the Empire for the purpose of protecting our food supply in time of war, the securing the goodwill and assistance of the Colonies, and the establishment of a self-contained area, which, by mutual co-operation between the parts, may strengthen the foundation of its united commerce.

BIRMINGHAM LOCAL SECTION.

INAUGURAL ADDRESS OF THE CHAIRMAN,

J. C. VAUDREY, Member.

(*ABSTRACT.*)

(*Address delivered December* 3, 1903.)

After thanking the members present for the honour they had done him in electing him their Chairman, Mr. Vaudrey said :—

In my address to you this evening, I would call attention to the importance of Birmingham and the district as a field for the particular branch of Engineering which our Institution represents. Birmingham, as a centre, has been the home of engineering work for over a century. Boulton and Watt made their first engines at Soho. The early practical results of the use of electrical energy were to be found in the electroplating works of the Elkingtons, and from that date the actual manufacturing of electrical apparatus in this district may be said to have commenced.

The existence in the town and district of machine makers and trained workmen has undoubtedly been helpful in the development here of a certain class of electrical work. Wolverhampton was probably the first town in the district to manufacture electrical machinery on a large scale. At the present time in Wolverhampton, Stafford, Rugby, Walsall, and this city are to be found many works engaged in the building of electrical machinery.

One cannot help noticing the immense variety of trades, akin or allied to the industry, which naturally result from a new business of this kind. The manufacture of the dynamo and the motor has brought in its train the manufacture of almost every type of electrical apparatus, involving a very great variety of trades. The importance of such trades to a city like ours is hardly to be overestimated. The Engineering Section of the University, when the new buildings at Bournbrook are completed, ought to be of great assistance; as it is here that the first principles overlaying the work will be taught.

We are constantly being told that we are beaten on our own ground by the better technically educated German, or, additionally more pushing American. This, to an extent, may be so, but certain militating circumstances have acted against us in this country, at any rate in our electrical enterprise. I am glad, however, to think that such do not play the important part they did. The circumstances, I consider, were these. Firmly established industries in England are not easily uprooted. When electricity as a means, first of illumination, and later as a source of power, became available, the trammels that were found here did not exist in America. There there was practically new ground; neither cities or towns possessed municipal gas plants, the greater

number of small towns having no other means of lighting beyond petroleum. Thus, at once, a field for electric lighting was open.

Here, on the contrary, most of our large cities own and work their own gas systems, and, naturally, could not but look with a certain amount of suspicion and disfavour on any system which would displace or modify the success of their own enterprise, and it was only after positive proof that electricity, as a method of lighting, had come to stay, that some measure of progress was made.

The same remarks apply to power used in the direction of traction. The United States offered an unlimited field for such a method of using power. Restrictions, found here, hardly existed, in country districts the tramway offering almost the only method of getting about. Before we in this country had realised it, hundreds of miles of electric tramway systems had been laid and were at work successfully in America.

The difficulty in England has been the position in which English Tramway Companies found themselves at about this date. In hardly a single instance were tramways worked by the municipalities. Under the Tramways Act, tramways leases were limited to a "life" of twenty-one years. The larger number of such leases had probably more than half run out; it was, therefore, impossible to expect any company, with a short tenure, to alter their systems from horse to electric traction, and as electric traction offered certain manifest advantages over horse traction, municipalities were unwilling, in most cases, to come to any terms whereby the leases could be extended so as to justify such expenditure, and this is responsible for the delay in the introduction of electric traction in most of our towns.

Standardisation, which is now put forward in such shape that manufacturers have only themselves to blame if they do not fall into line, will largely help us. If standardisation is coupled with real practical design and high-class work, we ought to have little to fear in competition.

I cannot emphasise too strongly the importance of manufacturers turning out thoroughly tried work. For some reason or other dynamo makers do not seem always to be able to manufacture their machinery with the same certainty of working condition as the machinist turning out an engine or pump. There are certain difficulties: calculable results are probably not as absolutely ascertainable in the dynamos as in the steam engines. Large commutators and wire windings present troubles in relation to temperature and expansion that do not exist in the engine building. The carbon brush and its holder are often also a difficulty, but it is everything that the maker of such machinery should assure himself that these details are thoroughly well worked out and tested before the machinery is put on the market. It is these and other questions which emphasise the importance of some common ground where experience, not only may be summarised, but the knowledge so gained accumulated. The Engineering Section of the University, when completed, should place at the disposal of engineers means of investigating and bringing to test problems not always soluble except in the laboratory. Practice is all important, but the

advantages of theoretical investigation, in combination with practice, will add to our knowledge.

No branch of engineering has made such rapid progress as the section we represent. One has not to look back more than a quarter of a century to find that electrical engineering, as a business, was largely non-existent. The development has been extraordinarily rapid, and it is hard now to find any business which is not more or less utilising electrical energy for lighting, power, or other purposes. There must, therefore, have been some strong reason, or manifest advantage to be gained by its introduction by the world at large; as such revolutions are not usual unless material saving is to be effected or marked improvements are apparent by use. What are these?

Advantages such as cleanliness, better methods of distribution, safety, etc., are so manifest, that for lighting purposes electricity has now become one of the important essentials of civilisation.

The advent of the motor came at a period when we were finding economies essential if this country was to hold its own against competing markets. The introduction of electrical machinery has undoubtedly had a most marked effect in calling attention to the utter want of efficiency in the use of power under older systems. All over the country were to be found, and still, I am afraid, in existence, factories working their steam plant in a most wasteful way, often four or five times the quantity of coal being used as should be necessary with modernised plants. In factories, therefore, the motor, as soon as its advantages were known, was bound to be adopted; nothing could keep it back. Any one building new works would never think of arranging the power for such works without seriously considering, and probably adopting electricity. Older works where possible, and where competition is being felt, are being remodelled so as to bring them into line with the new conditions.

The introduction of electricity has had the effect of entirely modifying engineering practice in regard to the distribution of power in works. Subdivision owing to the possibility of distributing power economically, has brought about methods of driving machinery which hitherto have been impossible, and I would commend close observation to the direction in which this is now tending. Tool makers and others should see how far it is possible economically to drive their special machines by motors direct. The day is passing by when a man will buy a lathe from one maker and a motor from another without any regard to the individual machines being designed as to their adaptability of being coupled together. The field that is open to the manufacturer in this direction is undoubtedly very large, and should not be neglected.

The use of energy for tramway and railway purposes is one of the extraordinary revolutions of modern times, and it is here, perhaps, where economy is most apparent. One of the requisities of our later civilisation is, without doubt, ready means of locomotion. Good roads, better than perhaps we have to-day, were one of the signs of the greatness of the Roman empire. Railways replaced the old coach roads; tramways replaced former omnibus routes. The horse-

tramway at one time seemed an ideal method of moving populations in large towns; the cost, however, of such traction as compared with that of electrically-drawn cars is so out of all proportion, that practically the horse-driven tramways will soon cease to exist. The extraordinary disparity in the cost per mile between these two methods of traction is such as to have entirely modified the relations between capital and the charges per car-mile, and thereby travelling has been considerably cheapened. I am not sure, however, that we are obtaining all the advantage we ought to do from this new system of traction. The town tramway systems in this country are being absorbed by corporations, ostensibly, for the reason the local authorities desire, as is termed "to be in possession of its own roads," and also, in many instances, to form a "day-load" for the electric supply station. As the tram system usually only includes the lines within the town area, the traffic, naturally, is heavy. The fares have been generally modified, but the enhanced traffic, owing to the better and more rapid service, is very large, and with the materially reduced working costs brought about by the use of electricity, it must be an exceedingly badly managed line that does not make a very handsome profit. I cannot help thinking, however, that sooner or later our towns will not be altogether gainers by a limited system of tramways within a town area. It is absolutely essential that instead of concentration, our cities should spread outwards. This can only be arrived at by an adequate system of tramways radiating from one common centre. I consider that in towns of this size a radii of tramways of not less than eight or ten miles ought to be attained, but unless the outlying districts form part of a whole, the making of such lines present considerable difficulties. The large profits which are possible in the centre of the town ought to help towards the working of the outlying lines; it is this that has rendered possible the working of railways under similar difficult conditions, and the sooner this is recognised by town authorities the better, or else we shall not have anything like the full advantage that electrical tramway systems should give us. It will only be by recognising this difficulty and arranging fair conditions with owners of the outside lines, that a full advantage of the tramway extension will be attained.

The use of power for tramway purposes has to-day, perhaps, attained more prominence than its use in connection with existing railways. Financial and other difficulties are probably responsible for its slower introduction on our railway systems. It cannot, however, be long before important work in this direction will be well in hand. A line of railway from Liverpool to Southport is being converted so as to work electrically; you are aware that the Metropolitan railways are in a similar condition of transformation. There would appear to be no economic difficulty in so working lines up to 50 or 60 miles long, and where the conditions are favourable, it can only be a question of a short time before railway engineers will avail themselves of the new power. You will see in this particular branch of engineering a whole field opened for new enterprise.

In calling attention to the general use of electricity, one must not

exclude to-day the important part it is playing, and going to play, in electrolytic processes, and here the chemist and the electrical engineer will come together.

In generally reviewing our branch of the profession, it must strike every one how widely the work of an electrical engineer is spreading itself. In future engineering will have to include in its scope the practice appertaining to the electrical section, as whatever branch of engineering a man may be working at, he must almost of necessity be brought into contact with the energy which has become well-nigh universal.

MANCHESTER LOCAL SECTION.

ELECTRIC TRACTION WITH ALTERNATING CURRENTS.

By A. C. EBORALL, Member.

(Paper read at Meeting of Section, December 15, 1903.)

Although the subject of the present paper is somewhat hackneyed, it is hoped that the present brief and general consideration of certain matters in connection with it may be of some interest, and at least give rise to a profitable discussion. It is proposed to deal firstly with some features incidental to the employment of three-phase currents for railway purposes, and then to refer to the subject of single-phase railway motors. Two years ago the latter were not in existence, but to-day the position is very different. The large amount of attention that has been given to single-phase motors by different engineers since that time has already produced results which seem to indicate that single-phase working may eventually take an important position as far as electric railway work is concerned.

Before proceeding to discuss specific questions in connection with the subject, it may be as well to say a few words with regard to the sphere of utility of alternating current working as far as electric traction is concerned. The latter has to be considered with regard to various classes of work, the requirements and conditions of which vary very greatly.

Apart from those cases in which the lines can be properly supplied directly from continuous current supply stations, and putting on one side the question of main line electric traction as being at the moment of academic interest only (at any rate, as far as this country is concerned), the following distinct classes of work have to be dealt with as everyday problems at the present time :—

(*a*) Urban and inter-urban tramways.
(*b*) Overhead, underground, and suburban electric railways.
(*c*) Branch line and light railways.
(*d*) High speed point to point railways.

As far as those lines of the first-mentioned class are concerned, it is obvious that three-phase working is out of the question; the mere fact of two conductors being necessary and the requirements of uniformity in the equipment of the line and rolling stock are more than sufficient, apart from all other considerations, to bring about this result. Again, even if the single-phase railway motor ultimately becomes an important factor in electric railway work, it would be hardly possible to contemplate a change from present practice. Even if special circumstances allowed of the requirements of uniformity being waived, such questions

as the inductive drop in the rails,* relatively inferior all round electrical performance, relatively greater cost and weight of the electrical equipment of the rolling stock, etc., would, it is thought, constitute disadvantages for this class of work which would not be made up for by the advantages of replacing the running machinery in the sub-stations by stationary transformers.

With regard to working costs, a certain economy naturally results owing to the substitution of transformers for rotating converting machinery in the sub-stations, but it is thought that this saving will not appreciably influence the total costs of operation, on account of the increased energy consumption in the secondary network. It is hardly likely that the all-round performance of any type of alternating current equipment will ever equal that of the corresponding direct current equipment—at any rate under the conditions usually prevalent in urban and inter-urban tramway work. However perfect the phase compensation of such motors may become, the losses in them and in the distributing system must be greater, other conditions being equal, while, on the other hand, the maintenance charges are not likely to be less.

With regard to (*b*), which implies, as a rule, the handling of a large number of trains running at short intervals for the greater part of the day, there is more to be said in favour of alternating current working throughout; but here again, in the present state of our knowledge, there can be little doubt which method is the better. The commercial success of such lines, which alone is the criterion by which the quality of the engineering portion of the work can be judged in the long run, turns very largely upon the question of rapid acceleration attained at minimum cost with the help of simple and flexible arrangements, and in this respect the direct current equipment is superior to the alternating current equipment, no matter what arrangements are made with regard to the starting and speed control of the motors. The better performance of the direct current motors in this respect outweighs the disadvantages inherent to extended systems supplied with energy from a considerable number of rotary converter sub-stations, and consequently recent decisions to employ direct current working on certain important suburban lines, now in course of electrification, are not to be wondered at.

But with regard to the classes of work enumerated under (*c*) and (*d*) above, where the distances are usually considerable and the acceleration periods are relatively insignificant, the case is quite different. For such work the disadvantages of alternating current working are by no means serious, while the advantages gained with regard to lower first cost and much smaller operating charges, are such that it is difficult to imagine lines such as those projected between Manchester and Liverpool, London and Brighton, etc., being laid out for direct current working. There can be little doubt but that electric traction on lines of this character, as well as on light railway

* For information bearing on this matter, see Mordey and Jenkin, *Proc. Inst. Civil Engineers*, 1902, p. 58; Huber, *Street Railway Journal*, June, 1902, p. 470, Herzog and Feldmann E.T.Z., 1900, Nos. 41 and 42.

TABLE I.

Leading Particulars.	Type of Motor. Three-Phase.	Type of Motor. Direct-Current.
Normal rating at 500 volts	80 B.H.P.	80 B.H.P.
* Momentary safe overload	200 „	160 „
Speed at 1¼ full load	717 R.P.M.	650 R.P.M.
„ 1/1 „	725 „	710 „
„ ¾ „	732 „	790 „
„ ½ „	739 „	940 „
„ ¼ „	745 „	1,250 „
Efficiency at 1¼ full load	89 per cent.	86 per cent.
„ 1/1 „	90 „	88·5 „
„ ¾ „	90·2 „	87 „
„ ½ „	90 „	83 „
„ ¼ „	86·5 „	74 „
Power-factor at 1¼ full load	85·5 „	—
„ 1/1 „	83·5 „	—
„ ¾ „	78·5 „	—
„ ½ „	66 „	—
„ ¼ „	45·5 „	—
Current at 1¼ full load...	113	174
„ 1/1 „	92	134
„ ¾ „	73	103
„ ½ „	58	72
„ ¼ „	44	41
† „ no load	38	—
Net weight, including gearing ...	1·7 tons	1·53 tons
Overall length	47 inches	38·5 inches
„ breadth	48 „	44 „
„ height	40 „	28 „
Length of air-gap	0·069 „	0·25 „
Relative cost of motor	1·25	1
‡ Relative cost of two controllers and the resistance	1·2	1

* For three minutes.

† Power-factor = 8·4 per cent.

‡ Series-parallel control for the direct-current equipment and control with rotor resistances only, for the three-phase equipment.

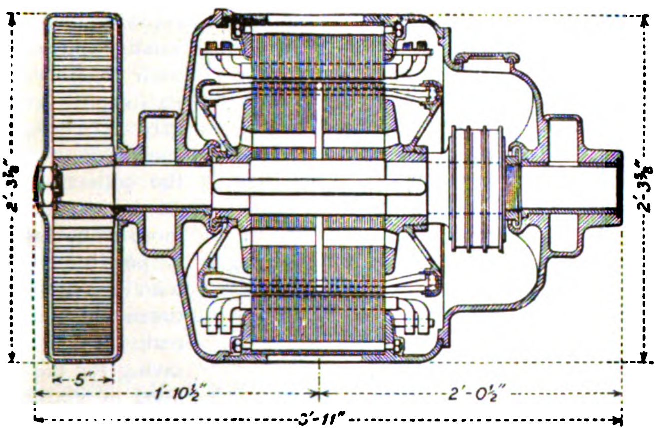
lines generally, will be carried out with alternating currents in the future, and it is in connection with this class of work that the following observations are more particularly applicable.

Three-phase Working.

Motors. In Table I. a comparison is given between typical standard high-speed 500-volt railway motors of the three-phase and direct current types, the former arranged for 25 cycles. The rating of each motor is 80 B.H.P. at 720 revolutions, the temperature rise of each motor not exceeding 75°C after a run of one hour at this load in either case. A section of the three-phase motor is given in Fig. 1, and the circle diagram for it in Fig. 2.

The table referred to shows at a glance the relative performance of the two classes of motor, although the direct current motor would certainly appear to somewhat greater advantage at a lower and more usual speed; the contrary would be the case, however, for the three-phase motor. The latter, it will be noticed, has an excellent efficiency curve, this having been specially aimed at in the design, and from this point of view the three-phase motor is quite as good, at all loads, as the best direct current motors of corresponding output.

It will be noticed, however, that the power factor at different loads has a lower value than the corresponding value for three-phase motors used for ordinary work, but this is wholly due to the relatively large air gap. The motor in question has a rotor having an external diameter of 17¼ inches, and for stationary work an air-gap length of 0·04 inch would be a usual and permissible value for this size of rotor. It is, however, too small for railway work, and increasing it by nearly



Pinion, 16 teeth, 5¾ in. Diameter, 720 Revolutions per Minute.
Gear Wheel, 72 teeth, 26 in. Diameter, 160 Revolutions per Minute.

Fig. 1.—Section through standard geared three-phase railway motor rated at 80 B.H.P. 720 revolutions per minute, 500 volts, and 25 cycles.

75 per cent. has naturally a large influence on the power factor. From the figures given above it will be seen that at full load 83½ per cent., and at half load 66 per cent. of the current actually taken by the motor is an energy current.

It will be seen from the table that there is no great difference between the weight and dimensions of the two types of motor, what difference there is being in favour of the direct current motor. But the cost of the three-phase equipment is considerably in excess of that of the direct current equipment, this being due, to a certain extent, to the expensive character of the controlling gear for the three-phase motors. As a matter of fact, the difference is even greater, when the cost of the entire car equipment is compared, principally on account of the expensive character of the wiring (especially in the rotor

circuits), but also on account of the additional apparatus, current collectors, switches, protective devices, etc., required in the three-phase case.

As to which is the better motor, considered from the engineering and cost of upkeep points of view, the three-phase motor has the advantage. With air-gaps of the order referred to above, no trouble is experienced in practice, provided that the bearings are properly proportioned in the first place and well looked after in the second. As far as the entire equipment is concerned, it must be remembered, moreover, that as a partial set-off to the very considerable disadvantages possessed by such a three-phase equipment with regard to economical speed regulation, and the collection of the currents from two or more trolley wires, it is possible to work with high pressures on the motors, and hence realise a considerable saving for the case of lines of considerable length. The limit in this direction really turns upon the question of the maintenance of effective insulation of the stators of the motors, for no matter what system of control is employed, no handling of high-pressure gear is necessary. For such cases as those included under (*c*) and (*d*), the stators of the motors can invariably be left on * and the entire control (except reversing) effected on the

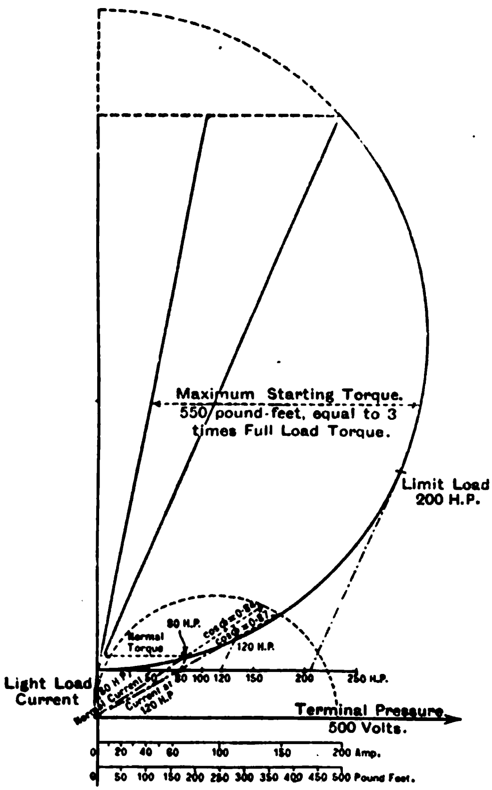


FIG. 2.—Circle diagram for the 80 B.H.P. three-phase railway motor shown in Fig. 1.

* This, the author believes, is what is done at Valtellina. Of course, for the class of work included under (*b*) this method of working would no longer be possible, on account of the continual waste of energy in the stators of the motors—for instance, the iron loss in the stator of the 80 B.H.P. motor, shown in Fig. 2, and referred to in Table 1, amounts to 2 kilowatts. The continual switching on and off of the stators of high-pressure motors could not be seriously contemplated, and hence the employment of such motors for this class of work is practically out of the question.

rotors; with infreqent stops and long runs this is entirely practicable, and for the rest, there is no difficulty with regard to the cutting off or reversal of the stator current at the termini, with the help of the excellent types of oil switches (requiring but little space) which are nowadays available.

But, although pressures of 3,000 and 6,000 volts are used for railways actually at work (and 10,000 volt railway motors have even been made), it is thought that the use of really high pressures for such work is open to serious criticism. It is by no means difficult to construct railway motors of large size to work at such pressures, but the effective maintenance of the insulation under the conditions prevalent in railway work is another matter. What with the effect of vibration on the durability of the insulation (which, it must be remembered, is always at a high temperature on account of the considerable and constant losses in the iron of the stator) and the difficulty of keeping out dirt, moisture, and oil, it is thought that the employment of pressures greater than about 2,000 volts is in general a mistake. At this pressure, and even at lower pressures, the energy necessary for the heaviest trains can be collected without difficulty by modified forms of the current collectors at present in use, and although the cost of the line and distributors is more, yet it is surely better to spend money once and for all on this part of the work than to spend it in repairs on the motors. Again, the indirect consequences of breakdowns in railway work are far more serious than in any other, absolute reliability being the first consideration. Owing to its nature electric traction cannot be so reliable as steam traction when it comes to really heavy work, and, knowing this, electricians should surely go out of their way to reduce risks of breakdown to an absolute minimum, even if it does cost more in the first place.

Speed Control. It is a trite saying that the speed control of the three-phase motor is its weak feature; unfortunately, as far as railway work is concerned, this is indeed the case. There is, of course, no difficulty in regulating the speed of three-phase railway motors, or in properly controlling or handling the trains and fulfilling service requirements, but the control of the motors is either accompanied by great waste or by considerable complication. These difficulties increase when rapid acceleration is an essential requirement, and it is for this reason that three-phase working for the class of work included under (*b*) is outside serious consideration.

Of the various methods that have been proposed for controlling the speed of three-phase motors, two alone are applicable to railway work, namely, rheostatic (rotor) control and tandem parallel control. The former method is in use on all the three-phase lines at present in operation (including the Zossen experimental line) with the exception of the Valtellina Railway, where tandem parallel control has been adopted by Messrs. Ganz & Co. This latter method of working was also proposed by the same firm in connection with the electrification of the Metropolitan District Railway in London, and the essential features of each method will now be briefly dealt with.

Unlike the direct current series motor, the speed of which adjusts itself automatically, in accordance with the torque which the motor is called upon to exert, the three-phase motor (or any induction motor) possesses the undesirable property, as far as railway work is concerned, of carrying all loads within its capacity at nearly the same speed; thus the 80 B.H.P. motor already referred to has a slip of only 13½ per cent. at a load of 200 B.H.P. The absence of inherent speed regulation for varying torque means that if left to themselves the three-phase motors on the cars will draw them up the steepest gradients on the line at nearly the same rate as on the level, and as this relatively large amount of power has to be provided for, the practical effect of this is that the capacity of the power station and sub-stations has to be in general about 30 per cent. greater than that of the corresponding direct current lay-out for a given running schedule on a given line.*

A reduction of the speed of the motors on the inclines by means of rheostatic control evidently does not help matters in this respect; the power that would otherwise be taken up by the train is now wasted in the rotor resistances, the net result being that, while a slower speed has been attained, the efficiency of the operation has decreased proportionately. The introduction of resistances into the rotor circuits is then analogous to the regulation of the speed of a shunt motor (working with constant field excitation) by means of resistances in the armature circuit. In both cases the energy input into the motor remains nearly constant, as for a given torque the current is nearly independent of the speed. In both cases the method of speed control in question is wasteful in the highest degree, and requires large and expensive resistances, which must be properly ventilated, and for which it may be a difficult matter to find the necessary room on the car. It follows, therefore, that rheostatic control of the speed of three-phase motors on the gradients of the line is useless from the point of view of power economy, and this is why it is never attempted in practice. In addition to the disadvantage relative to the capacity of the power plant already noted, it will be seen that the absence of inherent speed regulation on the part of the three-phase motor has the further disadvantage that the amount of the load on the motors cannot in general exceed a certain definite amount. Thus, for instance, on a line having severe gradients, it would in general be advisable to take advantage of the excellent overload capacity of the three-phase equipment to work the motors at an output well above full load on the steepest gradient, and this would mean (after making proper allowances for the varying state of the track and for possible variations in the motor pressure) that an emergency traffic could only be handled properly with the help of additional trains; the addition of a few more coaches to the standard trains might stall the motors on the worst gradient of the line. It is for this reason

* This is only correct, however, when generating plant of the standard pattern is employed, the maximum output of which is determined by the pressure drop on inductive loads. With the overcompounded generators referred to later on, the difference between the capacity of the direct-current and three-phase generating stations is nothing like so great.

that the motors on the goods locomotives on the Burgdorf-Thun line are provided with two speed gears, which is one way out of the difficulty. Another way is to work normally with such a margin of power on the motors that, notwithstanding possible variations in the condition of the track and in the supply pressure, considerable emergency loads can be handled on the worst gradients should the necessity arise. This means that the best property of the three-phase equipment—its great overload capacity—is not fully utilised in normal work, and that difficulties will probably arise in connection with getting the motors into the available space.

In all these matters the great influence of variations in the supply pressure on the performance of the motors must not be overlooked. Whereas the torque of the direct current equipment is unaffected by variations in the line pressure, the torque of the three-phase motors varies with the square of the pressure at their terminals. Thus, for instance, referring to the 80 B.H.P. three-phase railway motor shown in Fig. 1, the maximum load it can safely exert for a few minutes is 200 B.H.P. at 500 volts; at a pressure $7\frac{1}{2}$ per cent. below this it falls to :—

$$\text{Maximum B.H.P.} = 200 \times \frac{(462)^2}{(500)^2} = 172$$

It follows that the transformers supplying current should be so located along the track that on the gradients the full pressure is maintained on the motors under the service conditions; on the worst gradients it is desirable that this pressure should be even higher, which can be readily arranged for by arranging the transformers at such points with smaller transformation ratios. Another point is that an amperemeter and a voltmeter should form part of the equipment of the motorman's cab, and that their indications should be properly taken into account by the motorman at starting. Otherwise it might quite well happen, for instance, that careless handling of a train at starting on a gradient might stall the motors. The pressure at starting would fall, and with it the torque; giving the motor more current might not improve matters, as this might bring about such a further reduction in the pressure that the torque would decrease still more, and so on. Naturally, starting on gradients is to be avoided as much as possible, but the occasional pulling up of a train on a bad gradient has to be reckoned with.

The maintenance of a fairly constant pressure on the motor terminals has hitherto been one of the difficulties of three-phase railway work. For the class of work comprised under (*c*) and (*d*), implying a comparatively small number of heavy trains, the variations in the station output are of necessity very great. It may well happen, for instance, that the whole load suddenly comes on, and then falls to an insignificant amount very soon after. The load is, moreover, of an inductive nature (average power factor about 0·8), and a little reflection will show that under such circumstances the pressure fluctuations on the line must be very great. When the trains are on the gradients of the line, or starting from the termini, the motors must be worked at their proper pressure, as already indicated, and the generators in the

power station must, consequently, be excited to maintain this pressure on the lines during the periods of maximum load. Now at constant speed and excitation the best three-phase generators of standard design have pressure rises of 14–16 per cent. from full load to no load at a power factor of 0·8, depending upon the speed conditions, etc., while the step down transformers will not regulate better than 4 per cent. under the same conditions. If a drop of 5 per cent. is allowed in the trolley lines and feeders respectively, and an allowance of 3–5 per cent. made for variation in the speed of the engines from full load to no load, depending upon the type, it follows that the line pressure might vary in places by some 30 per cent., there being a corresponding pressure variation of the bus bar pressure in the power station. This assumes, of course, that the generator excitation remains unaltered, which in

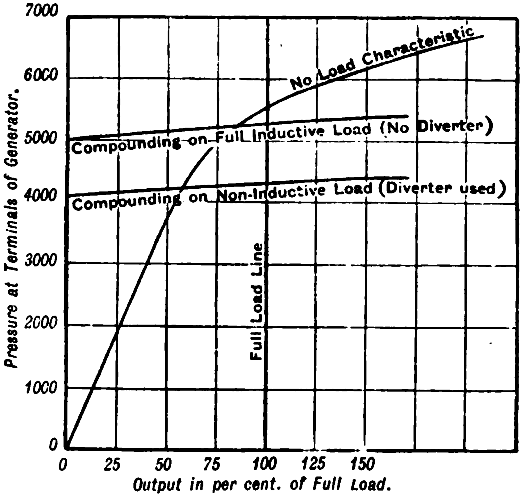


FIG. 3.—Compounding curves for an overcompounded three-phase generator of the revolving field type with Heyland field winding.

general would be the case. As an example of the amount of the pressure variations met with in practice (in this case due to a single train little more than half the weight of the standard train), the observed pressure curve shown in Fig. 4 (to be referred to later) should be noted.

Such pressure variations are very objectionable, not only from the point of view of the motors and of the lighting of the trains, but also on account of the additional stresses to which the insulation of the whole system is subjected. Fortunately they need no longer occur, as the problem of compounding three-phase generators, not only with regard to the amount of the load current, but with regard to its power factor also, has been completely solved. The new pattern of synchronous self-exciting revolving field generators* (standard machines with

* See the author's article on the subject in the *Electrician* for July 3rd and 10th, 1903.

Heyland field winding) are a technical and commercial success, and the problem of keeping the pressure fluctuations, due to varying load and power factor, within reasonable limits, has been solved. In Fig. 3 are given the compounding curves for a typical three-phase railway generator under the conditions of (*a*) a power factor of 100 per cent., and (*b*) a power factor of 10 per cent. at constant speed and excitation; the heavy over-compounding on the inductive loads naturally constitutes a great advantage for work of the character under discussion. The amount of the over-compounding for a given power factor can be adjusted once and for all as readily as for the case of standard direct current railway generators.

As the torque of the induction motor increases with the square of the pressure at its terminals, it follows that another way of getting over the above-mentioned difficulty, which arises in connection with the hauling of extra or emergency loads over the steepest gradients of the lines, is evidently to increase the temporary rating of the motors by increasing the motor pressure on the gradients (and at starting) either by means of a booster carried on the train, or by changing the connections of the motor windings from star to mesh. In this way the overload capacity of the motors would certainly be considerably increased by an amount depending upon the saturation, increase in leakage, etc., of the motors. But for high pressure motors such additional arrangements could not well be arranged for, while even for low pressure motors they are not desirable, on account of the extra complication thereby brought about, and also because of the great increase in the iron losses of the motor and the smaller power factor.

From what has now been said, the quality of the starting performance of three-phase motors controlled by rotor resistances will be readily realised. A starting torque per motor equal to nearly three times the normal full load torque is available for acceleration if necessary, provided the normal pressure is maintained at the motors, but it is accompanied by large losses in the rotor resistances. Still larger torques can be obtained for quicker acceleration, if desired, by increasing the pressure on the motors, but the result is even greater total losses. Generally speaking, the power consumption of well-designed three-phase motors during the starting period, when employing rotor resistance control, is of the order of 20 per cent. more than that required by the corresponding direct current motors, starting under the same conditions, with the help of series parallel control. This is for moderate accelerations—of about 6 inches per second per second; for very rapid acceleration, such as that often found with the latest lines of the (*b*) class, the difference in favour of the direct current equipment is still more marked. The necessary acceleration can be obtained, but at great cost.

It must be pointed out, however, that the characteristic fluctuations of energy during the acceleration period, incidental to direct current equipments using series parallel control are not nearly so marked in the case of the three-phase equipment using rheostatic control, on account of the uniform acceleration, and this is of real value, because it has its effect on the capacity of the sub-stations and on the comfort

of the passengers. Figs. 4 and 5, relating to tests carried out on the level on the Burgdorf-Thun and Liverpool Overhead Railways respectively, will serve to illustrate this point.

On the other hand, these tests serve to illustrate very well the difference between the performance of the two types of equipment as far as acceleration is concerned; whereas the direct current equipment has a high initial acceleration, which falls off as the speed increases, the acceleration with the three-phase equipment is nearly uniform throughout. Consequently, for the same average acceleration, the distance travelled over in the same time is considerably greater with the former than with the latter equipment. For certain classes of work such high initial accelerations are a necessity, and if this is

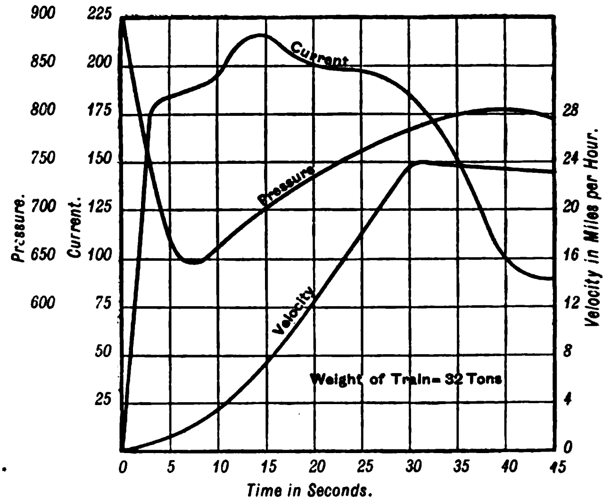


FIG. 4.—Acceleration test with experimental train, Burgdorf-Thun Railway.

required with three-phase equipments, rheostatic control of the motors is undoubtedly inferior to the method of tandem control referred to below. Large fluctuations in the power supplied to the train are a necessary accompaniment of very rapid initial accelerations.

So much for the rheostatic control of three-phase railway motors: there remains to be considered the alternative to it already referred to, namely, tandem parallel control. This method of controlling the speed of mechanically connected three-phase motors was devised and put into actual use as far back as 1892 by Messrs. Siemens & Halske,*

* The tandem, or cascade, or concatenation control of three-phase induction motors, as it is variously called, was actually devised by Prof. Gorges, the chief electrician of this firm at the time. Those interested in the theory and calculation of three-phase motors in tandem should refer to Dr. Breslauer's excellent little treatise on the subject, entitled, "Das Kreisdiagramm des Drehstrommotors und seine Anwendung auf die Kaskadenschaltung."

but it was not until Messrs. Ganz employed it on the Valtellina Railway in 1900 that it came to the front in connection with important work. As usually arranged, the rotor of the secondary motor is in series with the rotor of the primary motor, the stator of the former being short circuited at half speed, while that of the latter is, of course, directly on the lines. Intermediate speed regulation is obtained with the help of resistances in the stator of the secondary motor, although other intermediate speeds can be obtained without them by using special arrangements, such as arranging the mechanical connection of the two motors so that the speed of the one is greater than that of the other, or by the use of a different number of stator poles on the two motors, or by a combination of both methods, but such extensions of the original arrangement of tandem coupling have not yet been utilised in practice.

The tandem control of two mechanically connected three-phase motors which run at the same speed when in parallel is then analogous

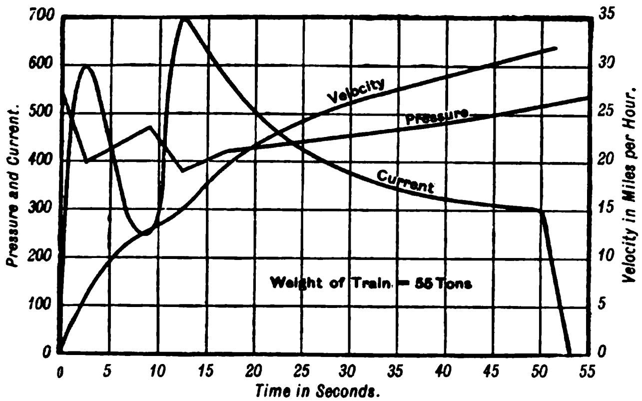


FIG. 5.—Acceleration test with experimental train, Liverpool Overhead Railway.

to the series parallel control of direct current motors, inasmuch as half speed can be obtained without the employment of resistances, but the analogy does not extend beyond this, as a little consideration will show. The curves of Fig. 6 illustrate what occurs when two such motors are in tandem; here the torque, current, efficiency, power factor, and slip curves are given (as functions of the load on the motors at constant pressure) for the case of two three-phase motors in tandem, and (dotted) for one of them operating in the usual way at double the speed. It will be seen that the maximum torque that can be exerted by the two motors together in tandem is somewhat less than the maximum torque which can be exerted by the one running alone; hence, as the speed is practically double in the latter case, it follows that the maximum output of the two motors in tandem is about one quarter of that of the two motors when in parallel, constant line pressure being assumed in both cases. It will also be noticed that for a given value of

stator current (primary motor) the total torque exerted by the motors in tandem is considerably greater than the corresponding value for the case of either motor working alone, and, further, that both the efficiencies and power factor for a given torque are considerably worse (especially the power factor) when the motors are in tandem. These are the principal electrical characteristics of three-phase motors connected in tandem, and running at half synchronous speed, or rather a little below it. When running above this speed, the stator of the primary motor being still connected to the lines, the combination returns power to the lines, which is a matter which will be referred to later on.

If a given motor equipment has to operate when all the motors are in parallel at an output nearly corresponding to the maximum torque of the individual motors, and if, moreover, the motors have to give this same torque when in tandem, it is clear from Fig. 6 that a means for

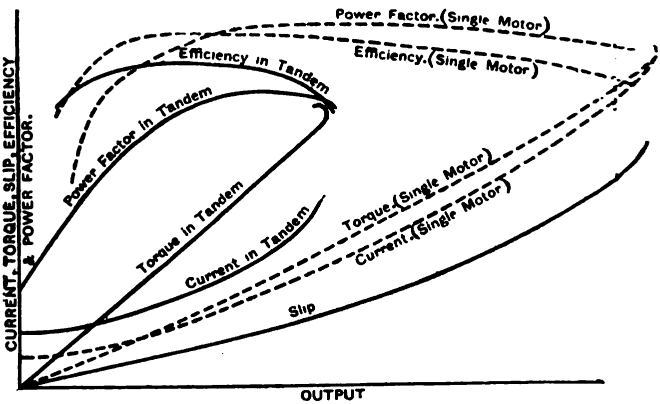


FIG. 6.—Characteristic curves for three-phase motors when working in tandem and singly.

increasing the torque of the motors when in tandem will have to be provided. Thus, for instance, the stator windings of the primary motor could be mesh connected while in tandem, afterwards being in star which would result in an increase of torque of 50 per cent. or thereabouts. A better arrangement, on account of the lesser complication, would be to increase the pressure during the period of tandem connection by means of a boosting transformer on the car or if step down transformers are used in connection with the motors (as at Zossen) by reducing the transformation ratio of these.* But however it is done, it means additional losses.

* Dr. Reichel (of Messrs. Siemens & Halske), who has done so much to make the work at Zossen a success, has worked out in detail several arrangements of this kind, with the object of increasing the torque of the motors when in tandem. The chief difficulty is to reduce the number of connections, and to get simple arrangements of the same, and of the controllers, especially when working with high pressure motors.

On the other hand, if all the motors are not required when in parallel, half of them running idle above half speed (except when braking), the double number of motors operating in tandem evidently gives a torque about equal to the maximum torque that can be exerted by half the number operating in parallel. This is, in fact, the Valtellina arrangement; here there are four motors of equal size per motor car, namely, two primary (3,000/330-volt) motors and two secondary (330/330-volt) motors. The secondary or low pressure motors are used only from standstill to half speed when accelerating, and from full speed to half speed when braking; during the rest of the time they are running idle, and of course out of circuit. Resistances are used in the rotors of the primary motors from half speed to full speed and in the stators of the secondary motors from standstill to half speed. With these arrangements, then, no auxiliary apparatus is necessary for bringing up the torque of the four motors in tandem to nearly the same value as when the two motors are in parallel.

Compared with the rheostatic control of three-phase railway motors, it is evident that tandem-parallel control offers considerable advantages from the points of view of rapid acceleration and economy; quite apart from the considerably diminished losses in the rheostats an appreciable amount of energy can be returned to the lines during retardation. At Valtellina this is some 12 per cent. (watts per ton mile basis), while, according to Messrs. Ganz, it would have been about 9 per cent. for the case of the inner circle on the Metropolitan District Railway. Of course, this regenerative action of three-phase motors can be taken advantage of under certain circumstances without using tandem control—the use of the latter merely makes it possible to do so under all circumstances. Thus, on Messrs. Brown, Boveri & Co.'s mountain lines the cars coming down can run somewhat above synchronous speed for long periods, and thus help to brake themselves by acting as generators. But in ordinary railway work the amount of energy returned to the lines in this way would be very small without the tandem arrangement. With the help of the latter the braking occurs over a wide range and below full speed. Thus, if the motors of a train running on the level at fifty miles per hour (synchronous speed) are switched into tandem connection, energy would be returned during the time taken to reduce the velocity of the train from fifty to twenty-five miles per hour.

But the advantages of the tandem parallel control in being able to run at half speed without rheostatic losses, and in returning power to the line during retardation, have to be paid for. In the first place, as already noted, both the efficiency and power factor when running in tandem are considerably worse than the corresponding values when the motors are working in parallel. At Valtellina the full load efficiency of the primary motors is 89½ per cent., that of the secondary motors is 90 per cent., while the efficiency of the combination in tandem at half speed is 80 per cent.; the power factors are respectively 92½ per cent., 94 per cent., and 77½ per cent. At the light loads the values (especially those of the power factor) are much worse. The reduced efficiency is due to the fact that for a given output the total loss in the two

motors in tandem is about double the loss in one motor alone, the total loss in the primary motor being about double that in the secondary motor. The reduced values for the power factor are due to the inductive character of the rotor circuit of the primary motor; the rotor current, instead of being practically in phase with the rotor pressure, is lagging considerably behind it, because the rotor is now short circuited on the rotor windings of the secondary motor, instead of being closed non-inductively. This is indeed the reason why the maximum torque of the two motors in tandem is so much less than that of the same two motors in parallel.

The above-mentioned electrical disadvantages of the tandem control are inherent to the method, and independent of the manner in which it is carried out. They become very serious indeed at usual frequencies, it being doubtful, as a matter of fact, whether tandem parallel control is commercially practicable at frequencies much above 25 cycles.

In order to get anything like good results with tandem parallel control, the power factor of the secondary motors must be very high—considerably above 90 per cent. In practice (apart from the employment of compensating arrangements) this means that the number of poles in the motors must be as small as possible, as, considering the relatively small diameter of the motors, it would not be possible to get power factors of this order if they had many poles. It would appear that six or, at the most, eight poles is about the limit for motors which have to work in tandem, which corresponds to frequencies lying between 15 and 25 cycles, the lower values being taken for gearless, the higher for geared motors, taking into account the usual maximum running speeds, wheel diameters, etc.

The other disadvantages possessed by the tandem parallel control may be said to be of a mechanical nature; their extent depends upon the manner in which the method is employed. If, for instance, all the motors are utilised during the period of parallel connection, they must all be alike, which means that when in tandem, separate rotor resistances will have to be used for the secondary motors, and these will have to be designed for the same pressure as that of the line. For instance, with a four motor 3,000 volt equipment four separate resistances would be necessary, namely, two suitable for 3,000 volts and two double ones for (for instance) 300 volts and heavy currents. Bearing in mind that if the same torque is required in tandem as in parallel, the flux in the stators of the primary motors will have to be increased, as already indicated, it will be seen that the equipment becomes not only excessively complicated, but very expensive as well.

If, however, the Valtellina arrangement is adopted, matters become greatly simplified; no high pressure resistances are required, and the two rotor resistances are employed alternately for the secondary and primary motors. Further, no boosting or other special arrangements are required for increasing the torque of the motors in tandem. But it must be admitted that the fact of half the motors being idle most of the time constitutes a certain disadvantage; clearly, on a fairly level

line with infrequent stops, the carrying round of so much dead weight would not be warranted. Again, it follows that, with this arrangement, the primary motors must work when in parallel well below the point of maximum load, in order that over-heating may be prevented, and, generally, such an equipment is altogether rather expensive.

Whichever form of tandem multiple control is employed the motorman has in general to operate two controller handles which are not interlocked, as it is not possible to pass directly from the parallel connection to the off position through the tandem position, in an analogous manner to the handling of a series parallel controller.

The commercial application of tandem parallel control in any form to multiple unit trains with two or more motor cars would be difficult, if not impossible. It is, of course, perfectly possible with rheostatic

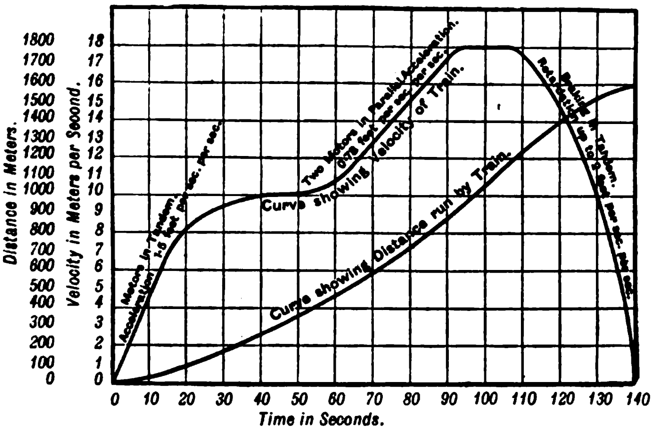


Fig. 7.—Acceleration test with experimental train, Valtellina Railway
Rolling weight: 54 tons.

control of the motors, and hence for those cases in which such trains are required, worked by three-phase motors, the system of control used would be in general decided by this point quite apart from other considerations. In connection with the operation of mechanically connected induction motors for such work, it is of importance to see that the difference in diameter of the various pairs of driving wheels is as small as possible, in order that the individual motors may properly share the load when operating at full speed on the level. Otherwise, as a little consideration will show, owing to the small slip under these conditions, the slower running motor might get badly overloaded. A comparatively small difference in the speeds would transfer the load to one motor, the other even acting as generator, being driven by the first.

Table II. and Fig. 7 may fittingly conclude these remarks on the subject of speed control. A comparison is given in the table between the starting performance of direct current and three-phase

equipments, as determined by actual trials. To extend the comparison, certain figures relative to the trials of a steam locomotive are also given. Regarding the relative performance of the electrical equipments, it must be pointed out that the comparison is not altogether a fair one to the three-phase motors, but it is the best that could be made, based upon actual tests. The two equipments are working under different conditions, and, moreover, the three-phase motors were not designed for such rapid accelerations as were the motors in the direct current cases. In the latter it is pretty clear that the series parallel control was worked for all it was worth. In Fig. 7, however (for which the Author is indebted to Mr. Blathy), the results are embodied of a special test made by Mr. Kapp on the Valtellina Railway, for the express purpose of seeing what results could be obtained by the use of the tandem parallel control in the form advocated by Messrs. Ganz & Co.

An inspection of the curves in Fig. 7 shows that the electrical performance of the equipment leaves little to be desired. The 54-ton train attained a speed of 59 feet per second in 95 seconds, which corresponds to an average acceleration of 0·62 feet per second per second, the acceleration with the two pairs of motors in tandem being about 1½ feet per second per second, while with the two primary motors in parallel it is about ¾ of a foot per second per second. These are excellent results,* while at the same time, partly on account of the energy returned to the line during the retardation period, the results with regard to power consumption are excellent, as will be seen from the following summary of this particular test made by Mr. Kapp:—

Test No. 5 (see Fig. 7).

Distance covered	5,280 feet.
Time from start to finish	140 seconds.
Highest velocity attained before braking	40·5 miles per hour.
Electrical energy supplied to car ...	20,574 k.w. seconds.
Power consumption per ton mile ...	106 watt hours.
Useful energy up to the moment (106 seconds from start) when brake was put on by the motors being switched in tandem	14,300 k.w. seconds.
Total energy supplied in the same time	21,960 k.w. seconds.
Efficiency during the above period ...	65 per cent.

The high efficiency of 65 per cent. is partly accounted for by the fact that at the end of the period in tandem, when the load is quickly

* Since writing the above, Mr. Blathy has informed the author that the motors at Valtellina would be capable of giving considerably greater accelerations if these were necessary; the only alteration that would have to be made would consist in a re-arrangement of the rotor resistances. Mr. Blathy states further that he has figured on accelerations up to aqout 3 feet per second per second for similar three-phase lines where high acceleration was necessary.

falling, the generating plant increased its speed, enabling the rotor resistances to be short circuited during a portion of the time, from 29·5 to 32·7 feet per second. On the other hand, when braking in tandem, the generating plant also increased its speed, being driven by the current returned from the car, and thus the frequency went up. This did not enable the car to return as much energy as would have been the case at constant frequency, and accounts for the smallness of the energy (1,386 kilowatt seconds) returned to the line.

From Table II. and Fig. 7 it will be seen that, on the whole, the figures for the three-phase equipments are excellent, but with rheostatic control they would not compare so favourably with the direct current equipments at the higher accelerations; with tandem parallel control, while there is little to choose between the two equipments, the good performance of the three-phase equipment is attained at the expense of the disadvantages which have already been referred to.

From what has been said it is clear that with regard to which is the better system of control for three-phase equipments, the rheostatic or the tandem parallel, this depends to a great extent upon the class of work for which the equipments are employed. But the Author thinks, in the present state of knowledge, that the use of alternating currents should only be contemplated for work of the class comprised under (*c*) and (*d*), and then only when the length of the lines is such that many converting sub-stations are necessary. For these classes of work, the inefficiency of the rheostatic control is of relatively small importance, and it is thought that its use is preferable, notwithstanding the disadvantage of having to take the worst gradients at full speed. If, however, for any reason, three-phase working is employed for cases where it is necessary to attain rapid accelerations with economy, the tandem parallel system of control must be used, and of the two forms in which it can be applied, that advocated by Messrs. Ganz is, it is thought, preferable on account of its greater simplicity, this point outweighing the disadvantage of the exceedingly heavy character of the electrical equipment.

However, an attempt has been made to put forward the characteristic features of each method of control, and to dwell rather upon the weak points of each, as, whichever method is selected in any particular case, these are the points that require the most attention.

Single-Phase Working.

The desirability of single-phase working for lines of the (*c*) and (*d*) classes is self-evident, assuming that suitable motors are available. As the whole question turns upon the motors, it is now proposed to consider very briefly the various types of single-phase motors at present available. These types, apart from synchronous motors, are as follows:—

1. Pure induction motors.
2. Series motors (Lamme, Finzi).
3. Repulsion-induction motors (E. Arnold, Deri, Schuler).
4. Repulsion-series motors (Latour, Eichberg-Winter.)

BLE II.—COMPARISON OF ACCELERATION AND POWER CONSUMPTION TESTS CARRIED OUT ON THE LEVEL WITH DIRECT CURRENT AND THREE-PHASE ELECTRICAL EQUIPMENTS.

No.	Installation.	Nature of Supply.	Total weight of train in tons.	Maximum speed in miles per hour.	Normal rating of motors in B.H.P.	Average acceleration (feet per second per second).	Average watts per ton during acceleration period.	Watt hours per ton mile during acceleration period.	Watt hours per ton mile during acceleration and retardation period.	REMARKS.
1	G.E. Trials (Schenectady.)	Direct current at 575 volts.	71·5	47	8 × 165	0·95	6,500	170	129	Each of the eight motors employed is rated at 3,000 lbs. pull at 23 miles per hour and with 280 amps. Average speeds 34·6 and 32 miles per hour hour respectively. Two motor cars with four motors per car.
2	Ditto.	Ditto.	118·5	43	8 × 165	0·79	4,650	133	99	
3	Liverpool Overhead Railway.	Direct current at 500 volts.	46·3	32	4 × 100	0·88	4,000	170	137	Two motor cars with two motors per car, each rated at 2,000 lbs. at 25 miles per hour and 160 amps.
4	Burgdorf-Thun Railway.	Three-phase current at 750 volts and 40 cycles.	70·0	24·5	4 × 65	0·46	2,570	195	—	Rheostatic control. Full load speed of motors 585 revolutions. Gear ratio 1 : 2·96; driving wheels, 40 in; weight of complete motor, 3,400 lbs.
5	Ditto.	Ditto.	55·0	24·5	4 × 65	0·63	3,450	240	—	
6	Valtellina Railway.*	Three-phase at 3,000 volts and 15 cycles.	82·5	40	4 × 150 (two motors idle above ½ speed.)	0·38	2,770	—	65	Drawbar pull per gearless motor with 46-in. wheels at 300 revolutions = 2,200 lbs. Pull at starting in tandem with idle motor 3,960 lbs. per pair of motors.
7	New York Central. Steam Locomotive trials.	—	130·0	51	Drawbar pull = 25,900 lbs.	0·86	—	—		Locomotive specially built to meet requirements of suburban traffic.

* On the Valtellina Railway, the four motors are connected in tandem up to half speed, whilst from half speed to full speed two are idle, the other two being in parallel; when braking the four motors are in tandem from full speed to half speed.

The first mentioned class of single-phase motors can be dismissed in a few words, as they cannot be directly applied to electric traction purposes. Their efficiency and power factor are less than is the case with the corresponding three-phase motors, their speed cannot be regulated within commercial limits, their overload capacity is relatively small, and their starting performance is indifferent. The best that can be done in the latter respect, under favourable conditions with regard to frequency, is full load torque with 1¾ times full load current—this with the help of a rotor resistance and a good phase splitting arrangement. Such motors could therefore only be used indirectly as far as electric traction work is concerned, although they possess the advantage (unlike the motors of the other three classes) of being without commutators.

B. J. Arnold has proposed to utilise such motors for traction purposes, with the help of an air-compressor on the car, the object of the latter being to get over the starting difficulties as well as those of speed regulation. The motor is always running on load, this consisting of the car and the compressor, or the latter alone, as the case may be. The Oerlikon Company, on the other hand, has suggested the use of single-phase induction motors in connection with heavy locomotive work, the motor working from a single overhead conductor at 15,000 volts, and forming part of a direct current motor generator combination carried by the locomotive, which supplies current to separately excited direct current motors on the car axles. Although a certain amount of experimental work has been done in connection with each of these suggestions, it is hardly likely that such methods of working will come into general use.

The single-phase motors comprised in the second class are what used to be known a good many years ago as "laminated field" motors; before the advent of the single-phase induction motor quite a number were built in this country for the 83 and 100 cycle supply circuits then in existence. At that time they were built in very nearly the same way as the corresponding direct current series motors, the principal difference in the design being the substitution of a laminated field structure for the standard cast or wrought-iron field frame. Such motors possessed every fault it is possible for a commutator motor to have—low efficiency, overheating, and bad sparking being the worst—while being abnormally heavy for their output, mainly on account of their very low power factor.

After remaining in the background practically since 1893 these motors have recently reappeared as possible railway motors. By reducing the frequency to 15–20 cycles (and with the help of sundry auxiliary devices which have been more or less well-known for years), aided by careful designing, a very good imitation of the direct current series motor has been obtained, which is likely to come to the front in the future. Up to the present, as far as the Author knows, by far the best results have been attained with these series motors by Dr. Finzi, the trials of whose 15 cycle 160 volt tramway motor are fully dealt with in an article in the *Electrical Review* for November 13, 1903.

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The following are the principal difficulties connected with the

design of single-phase series motors, together with the methods which are adopted in order to get over them :—

1. *Sparking.* The coils, which are short circuited as the commutator segments, to which they are connected, pass under a brush, become the seat of very heavy induced currents, as these coils are cut by the alternating field flux. These heavy short circuit currents, being interrupted when the segments leave the brushes, cause heavy sparking; moreover, they tend to demagnetise the field system, and also waste energy in the short circuited coils, brushes, etc.

The remedy is to connect the armature coils to the commutator by means of nickeline or other resistance strips (Finzi), or to employ a Weston winding on the armature (two independent windings alternately in circuit), to employ the proper width and quality of brush, and to reduce the frequency.

2. *Relatively Low Efficiency.* This is due to the fact that both the iron and copper losses are considerably more than in the corresponding direct current motor or induction motor. In the latter, not much more than half the total weight of laminated iron is traversed by a flux of the full frequency (at speeds near synchronism), while for the case of the series motor the entire weight of active iron comes into consideration. Again, owing to the extra losses in the commutator connections, brushes, etc., and to the rather low power factor at heavy currents, the copper losses are increased.

A reduction in the frequency improves matters.

3. *Low-Power Factor at Heavy Currents: Armature Reaction.* The field and armature windings in series offer an impedance to the alternating current traversing them, and the greater the value of this current, the more it lags behind the supply pressure; in other words, the worse the power factor. The latter in fact falls from a high value at light loads to zero at standstill. As far as the field system is concerned, the only remedy is to reduce the frequency as much as possible; but with regard to the armature, seeing that it is the armature flux that causes not only the inductive E.M.F. in the armature, but a reaction on the field system as well, it is advisable to reduce it to a minimum. This can be done either with the help of damping coils (Stanley) or by saturating the pole shoes (Lamme) or by dividing the poles in the axial direction by means of slits (Finzi). The first-mentioned arrangement tends to wipe out the armature flux altogether, and thus to get rid of field distortion and armature reactance; the second and third arrangements tend to reduce the armature flux in amount. As far as the inductive E.M.F. of the armature winding is concerned, this decreases with the frequency.

It will be seen from the above that the real remedy for nearly all the troubles consists in lowering the frequency as much as possible, which, as already stated, is what is being done by the present constructors of these motors. The only disadvantage of this, as far as railway work is concerned, lies in the more costly nature of the generators and transformers; from the point of view of the inductive drop in the rail return, it is of course directly beneficial.

For the rest, the alternating current series motor has speed, torque,

and other characteristic curves generally similar to those of the direct current series motor, except that the maximum values of the current and torque occur at a point which is relatively much nearer to the normal values.

Railway motors of this type necessitate step down transformers being carried on the car, as they can only be worked at low pressures ; the speed control is affected by varying the transformation ratio and is hence very economical, this feature of the motor tending to compensate for its relatively lower efficiency.

The motors of the third class are mixed action motors ; they start as repulsion motors, and after a certain speed has been attained, all the segments of the commutators are short circuited, and they continue to run as induction motors. The type originated with Prof. E. Arnold, under whose patents the Wagner Company of America has built many motors for ordinary industrial purposes, but as the Schuler motor is the best representative of the class, it will suffice to refer to it in particular here.

The characteristic features of the pure repulsion motor are its good starting performance and poor running performance. The efficiency and power factor are both low, and for a given output the motor is relatively very heavy. On account of this, and especially in view of the fact that the change can be readily effected, it was but natural to change it into a pure induction motor at or near normal speed, because near synchronism the single-phase induction motor operates at its best. Arnold does this by short circuiting the commutator segments by a centrifugal device (and raising the brushes simultaneously), while Deri does it by altering the number of stator poles in a similar manner. In both cases the conversion is suddenly performed, and accompanied by undesirable current fluctuations ; there is, moreover, a want of flexibility about it which puts such motors out of the question as far as traction work is concerned.

In the Schuler motor, however, the transition from repulsion to induction motor is almost imperceptible, as it is effected with the help of slip rings and a star connected rotor resistance, through which the rotor windings are gradually short circuited. The commutator brushes remain short circuited, and more or less current passes through them, in accordance with the manipulation of the resistance ; at normal speed, practically no current passes through them, as the rotor windings are, at this speed, completely short circuited at the slip-rings. At speeds intermediate between standstill and synchronous speed, part of the rotor current passes throught the short circuited commutator brushes, and part through the rotor resistances ; under these conditions the rotor is working partly as a repulsion motor, partly as an induction motor.

To sum up, the Schuler motor presents the possibility of starting with a large torque without an excessive current consumption, and of speed regulation over a long range with smaller losses in the rotor resistances, than would be the case with the corresponding three-phase motor operating under similar conditions. Its efficiency, power factor, and overload capacity are, however, much inferior to the latter, while

with regard to commutation, it is comparable with the series motor, and what has been said in connection with the commutation of the latter is equally applicable to it. It is thought that while the Schuler motor is exceedingly well worked out, and the best of its class, it will not find a place in single-phase traction work, or at any rate that it will not take precedence of the pure series motor, or of the series repulsion motors referred to below; its sphere of utility is more likely to be in connection with elevator and similar work. At the same time, it must be pointed out that the addition of an efficient compensating arrangement to it, so that it would work at a power factor approaching unity over its whole range, would alter the situation; in any case, it has one advantage over the series motor, namely, that no step down transformer is required. Its stator construction is that of a standard three-phase motor with one phase of the winding always out of use, and the limiting value of pressure would be the same. Its rotor, which in construction resembles the armature of a rotary converter, must always work at low pressure.

This ability to work directly at high pressure is a property also shared by the fourth class of single-phase motors—the Latour and Winter-Eichberg motors. These motors are partly repulsion motors, partly series motors, and are the most interesting, and perhaps also the most promising single-phase motors that have yet been devised. They differ in two important respects from all other series or repulsion motors—the power-factor is nearly unity under all conditions of working, while the field flux is produced by the rotor instead of by the stator, the ampere-turns of the latter being less than those of the former.

In Fig. 8 (*a* and *b*) the Latour and Winter-Eichberg mixed action motors are respectively indicated in diagrammatic form, and, as will be noticed, there is no essential difference between them; indeed, these designers seem to have reached practically the same point by different and independent paths. By supplying the commutators at constant pressure (if necessary, through a step down transformer of suitable size) instead of variable pressure, as indicated in the figure, motors can be obtained the performance of which is analogous to that of direct current shunt motors, and such motors would be applicable to ordinary industrial work, as Latour has pointed out.

The windings indicated in Fig. 8 (two-pole motors being represented for the sake of clearness) correspond to series wound direct current motors, and hence will be alone referred to in connection with the subject of electric traction. As far as constructional features are concerned, the stators of these motors are just like the stators of ordinary induction motors. Latour, however, prefers to distribute the winding all round the periphery to form a closed circuit, there being thus (in the two-pole motor) two parallel paths traversed by the single-phase current. The rotors are simply specially proportioned direct current armatures with amply dimensioned commutators of many segments; these commutators have to be arranged to work at 200 volts between brushes, or less, which can be readily arranged for if the current transformer of Winter and Eichberg is provided.

Consider, for instance, the motor of Fig. 8A, with the brushes *a*, *b*, removed, and the single-phase current traversing the stator only. A

pure repulsion motor of favourable design would result, the characteristics of which would be (as Latour has shown) an excellent torque at starting, which decreases with the speed, together with perfect commutation at synchronous speed. As already indicated, however, the power factor of such a repulsion motor is very low, while unless special arrangements are adopted, the motor sparks badly below synchronism. These defects disappear almost completely, however, directly the armature with its short circuited brushes *c d* has current from the external circuit led into it (directly or indirectly) by means of the brushes *a b* placed at right angles to the brushes *c d*, which arrangement results in a repulsion-series motor. The motor now has a power factor of nearly unity at all loads, a starting torque equal to that of a three-phase motor, but not requiring resistances in order to obtain it, a possible speed

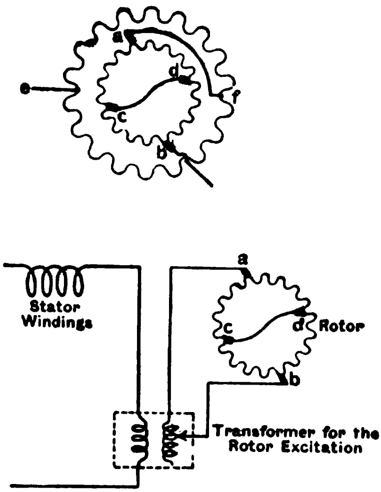

FIG. 8 (*a*) and (*b*).—Diagrammatic representations of Latour and Winter-Eichberg single-phase repulsion-series railway motors.

variation over wide limits by varying the pressure at the brushes *a b*, and excellent commutation under all conditions at these brushes. Working under fixed conditions of supply, the speed and torque characteristics are generally similar to the corresponding characteristics of the direct current series motor.

Briefly, the current C_1 passing through the rotor from outside by way of the brushes *a b* produces a rotor flux which, in conjunction with the rotation of the rotor in it, causes a current C_2 in quadrature with C_1, to flow through the rotor by way of the short circuited brushes *c d*. The flux due to one component of the current C_2 cancels the stator flux, and thus renders the stator windings practically inductionless, and, moreover, by doing away with the stator flux, allows of perfect commutation at the brushes *a b*, as the heavy currents in the short circuited coils which would otherwise be caused by induction from the stator, are

now no longer present. Again, the magnetic flux along *c d* forms, with the flux along *a b*, a resultant flux which rotates nearly synchronously with the rotor, and the latter therefore also becomes nearly inductionless, just as is the case with the rotor windings of an induction motor operating near synchronism. It would appear that the only serious difficulty with this motor is the commutation at the brushes *c d* at speeds below synchronism, but the difficulty can be got over perfectly well at frequencies of the order of 25 cycles, with the help of the means already alluded to.

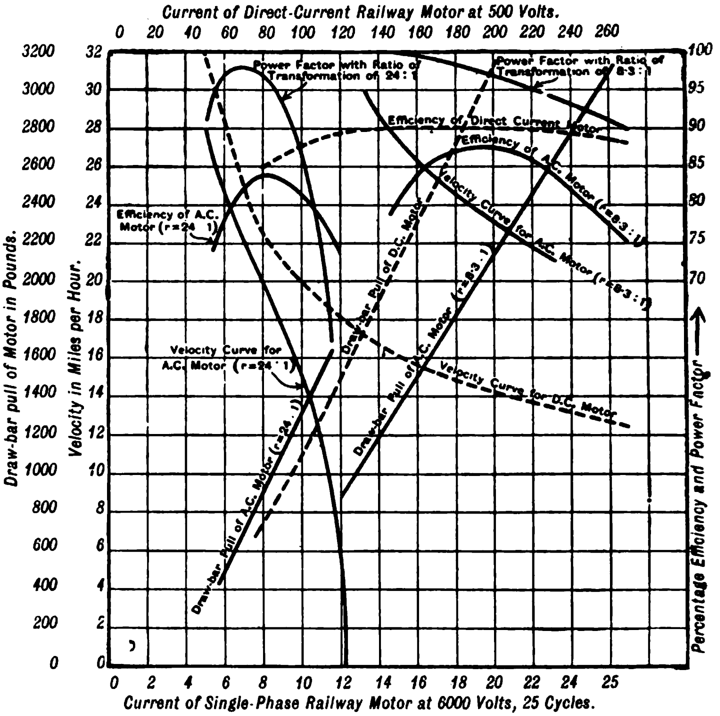

FIG. 9.—Curves of 125 B.H.P. Winter-Eichberg railway motor, and of 125 B.H.P. G.E. direct-current railway motor.

As far as the Author knows, the only difference between the above motor and that of Winter and Eichberg, apart from constructional details, is that in the latter motor, the rotor is indirectly in series with the stator, as indicated in Fig. 8B. The use of the current transformer for supplying the brushes *a b* allows the stator to be worked at the full line pressure, no step down transformer being therefore required on the car; at the same time the entire switching and speed control is performed on the low pressure side—that is to say, in the secondary circuit of the current transformer. Naturally the arrangement lends itself well to multiple unit trains, the control being characterised by the

absence of rheostatic losses, and by the permanent connection of the various motors in parallel.

In Fig. 9 are given the results of some tests made by the Union Company on an experimental coach fitted with motors of Messrs. Winter and Eichberg's design. This coach has been running since August on a short line near Berlin. The coach weighs 52 tons in running order, and is equipped with two motors of 125 B.H.P. at 6,000 volts and 25 cycles. The weight of the entire electrical equipment is about 6 tons. In Fig. 9 are also given the curves (shown dotted) for the new 125 B.H.P. motors on the Central London Railway* in order that a ready comparison may be made between a standard direct current equipment of latest design and the single-phase equipment. For the latter, it will be noticed that two sets of curves are given. These correspond to the maximum and minimum transformation ratios employed, and hence indicate the conditions prevailing at light and heavy loads respectively. Between these limiting transformation ratios of 24 : 1 and 8·3 : 1 there are a number of others, the motor having similar characteristic curves for each. It will be seen that the efficiency of the single-phase motor is not much below that of the direct current motor, while the speed control is equally flexible. The power factor, moreover, is good over the whole range, while the commutation under different conditions is stated to be excellent.

Whether one or other of these types of single-phase railway motor will eventually succeed in taking the place of other motors for the classes of railway work more particularly referred to in this paper, remains to be seen, but from what has been said above it will be recognised that a lot of good work has been done in this direction during the last year or so. The commercial application of such motors will largely depend upon the quality of the commutation under traction conditions, and with regard to this it must be borne in mind that the difficulties are, and always will be, very much greater than with direct current motors. But one thing is quite certain—what with the new type of compounded alternators, the compensated three-phase motors and the various new single-phase motors, electrical engineers will have to reckon with the commutator in alternating current machinery, and some modification of certain ideas at present held may confidently be expected in the near future.

* "The Central London Railway," by H F. Parshall, E. Parry and W. Casson—*Traction and Transmission*, vol. vii.

ORIGINAL COMMUNICATION.

GAS POWER.

By J. Emerson Dowson, Associate.

Development of Gas Power.

In recent years the development of gas power has been conspicuously marked, a fact due in large measure to the better understanding of the thermodynamic problems involved. I can remember the time when the makers of gas engines sought improvement almost exclusively in mechanical devices, and when less attention than it deserved was given to the behaviour of gases under the varying conditions of temperature and pressure which must necessarily occur in the cylinder before and after each explosion. In this country it was Mr. Dugald Clerk who first thoroughly investigated the subject as a chemist and physicist, and his published writings led to a better appreciation of the somewhat complicated and difficult problems involved. By way of illustration, one should remember that in the early days of the Otto engine the compression of the explosive mixture of gas and air, before ignition, was only about 35 lbs. per square inch; it is now seldom less than 90 lbs., and is often higher. Formerly the mean pressure in the working stroke was about 70 lbs. or less, with good town gas, whereas it is now 90 lbs. and more per square inch; even with producer gas these high pressures are now obtained. It was within the province of the engineer to devise means for doing this, but the physicist taught him that it was necessary.

Then, again, with regard to the plant which is to make gas for the engine (in cases where ordinary town gas is not to be used) there are several important theoretical points to consider, as well as the practical application of the principles involved. Everybody knows that a steam engine must have a good boiler to work with it, so that the combination of boiler and engine may convert as much as possible of the heat energy of the fuel into useful work. In my opinion it is still more important to consider all that makes for efficiency in the gas plant, as the changes to be effected in the latter are not as simple as the mere conversion of water into steam, while at the same time the quality and condition of the gas, its temperature and pressure, should be as nearly uniform as those of steam. Practically the gas plant is to the gas engine what the boiler is to the steam engine, and if the plant is not properly designed to insure a continuous production of suitable gas for the engine, the efficiency of the latter, as well as that of the gas plant, is necessarily lowered; but even now there are comparatively few makers of gas plants who give sufficient attention to the theoretical questions involved. It is fairly easy to make producer gas for furnace work, and thanks to the adoption of regenerative furnaces,

as advocated by the late Sir William Siemens, this use has extended enormously; but the gas for a gas engine should have a higher calorific power than is sufficient for a furnace, it should be uniform in quality, free from tar and other impurities, and it should be produced as rapidly as it can be consumed, in a plant occupying a comparatively small ground space.

All these questions are now understood better than they were, and more and more attention is being given to them. It is doubtless true that to a certain extent we are still in a process of evolution, but the broad fact remains that notwithstanding all shortcomings the spread of gas engines and gas plants in many countries has been great indeed during the last few years, and undoubtedly they have come to stay, at least until some now unforeseen and revolutionary change in power production is upon us.

I could touch on many interesting points connected with the design of the gas engine and gas plant, but as electrical engineers, we are not so much concerned with these questions, as with their working, and the practical results which can be obtained with them. All cannot be dealt with in a single paper of moderate length, and I think it will be best if I address myself chiefly to the practical working of installations with gas power, so that we may judge for ourselves how far, and in what cases, it may be desirable to adopt gas instead of steam.

Gas and Steam Engines.

Although I am an advocate of gas power, I am not prepared to say that a gas engine is as simple in its construction or management as a steam engine, taking good types of each. I would go further and say that until we have more experience of gas engines developing over 500 or 600 B.H.P. each, it will be well for electrical engineers to specify clearly and definitely the conditions which *must* be fulfilled. In Belgium and Germany much larger gas engines have been made than in this country, chiefly to work with blast furnace gas, and it is only lately that attention is being given to these large powers in England. Some enthusiasts have already prophesied the downfall of the steam engine, but it will probably be best to await the result of actual experience, and for the present to recognise that the steam engine and the gas engine each has certain well defined characteristics, and that each is more or less suitable than the other for certain installations. It may even be that the two may work together in a central station, under certain conditions, and later on I will again refer to this suggestion.

Working of Gas Plant.

As to the gas plant, if it is properly designed and built, it should not be more difficult to manage than a steam boiler and its accessories. It can be worked by the same type of man as is required for the steam plant, and the attendance and wages required in each case are about the same; but the maintenance and repairs of the gas plant are much less than those of the boiler. Speaking with many years' experience of gas plants of my own design, I can say with confidence that the following

may be taken approximately as a fair allowance for the repairs and maintenance (exclusive of painting):—

Repairs and Maintenance.

For 100	B.H.P.	plant	about	£4	per	annum.
„ 200	„	„	„	£6	„	„
„ 300	„	„	„	£9	„	„
„ 400	„	„	„	£12	„	„
„ 500	„	„	„	£15	„	„

At Leicester the official returns (see Table A) show that the repairs and maintenance of gas plant, engines, and electrical plant with several small units average 0·079 of a penny per unit generated. At Walthamstow (Table B) the same items average 0·03 of a penny. I will not attempt to estimate the repairs and maintenance for steam power on the same scale of working, but there cannot be any doubt as to these charges being less with gas power than with steam power.

Apart from the question of repairs, the comparison of gas power with steam power seems to resolve itself into one of saving water and fuel, the cost of wages, oil, stores, and sundries being about the same in each case.

Water Consumption.

The water required for a well-arranged gas plant is about ¾ gallon per B.H.P. per hour. Water is also required for cooling the cylinder of the gas engine, but if there is a cooling tank, with a flow and return from the cylinder, the actual quantity of water consumed is insignificant. The general result is that the gas plant requires considerably less water than a steam plant of the same power.

Fuel Consumption.

As to the fuel consumption, I think it should be considered under two heads, the consumption per H.P. while the plant is running, and the fuel consumed during the stand-by hours. In central station returns it is not usual to make this distinction, and the fuel consumed per unit generated usually includes the stand-by and all other losses, but I have had several special tests made for the purpose of this paper, and I will presently deal separately with the stand-by loss with steam and gas power. I will now give the general results sent me by trustworthy authorities from four typical installations:—

1. *Leicester.*—Since 1893 the Midland Railway Company have used gas power for about 140 arc and 320 incandescent lamps for lighting the joint railway station and goods yard of the Midland and London and North Western Railways. There are six Crossley Engines, capable of developing a maximum of about 300 B.H.P., and the dynamos are belt-driven. The plant was put in on the recommendation of Mr. Langdon, late chief electrical engineer of the Midland Railway, and its practical working has from the first been under the immediate superintendence of Mr. W. Goodchild; I believe I am right in saying that although this is not now an up-to-date installation, the fuel con-

sumption at this station is lower than that at any of the steam power stations of the Midland Railway Company. In Table A I give details of the working costs sent me by the present locomotive superintendent at Derby, Mr. R. M. Deeley.

TABLE A.—LEICESTER.

Returns for five months, January to May, 1903.

Total B.T. units generated 200,497.

Average fuel consumption, 3 lbs. per unit generated, including all stand-by and other losses.

Works cost per unit generated:—

*Coal and other fuel		0·245 penny.
Oil, waste, water, etc.		0·039 „
†Wages for generation	Gas plant ... 0·146 Engine room 0·437	0·583 „
Repairs and maintenance of gas plant, engines, and electrical plant		0·079 „
Total		0·946 „

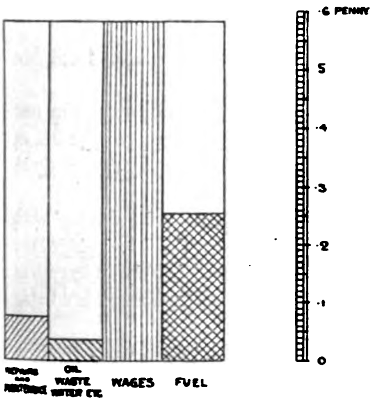

FIG. A.—Working Costs at Leicester.

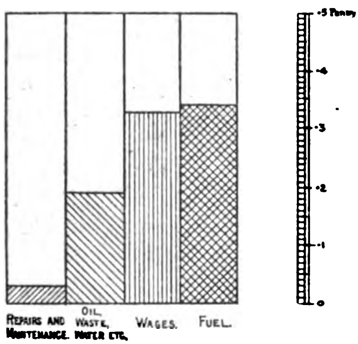

FIG. B.—Working Costs at Walthamstow.

2. *Walthamstow.*—This is a central station belonging to the Urban District Council. In 1901 they began with two sets of 75 kilowatts each, in 1902 they added two more, and in the same year they added three sets of 200 kilowatts each; others are about to be added. The engines are of the Westinghouse make and are driven with Dowson gas made from small anthracite peas ($\frac{3}{8}$ in. to $\frac{3}{4}$ in. cube); the dynamos are coupled direct to the engines. The station now supplies current for

* Coal cost 15s. per ton exclusive of carriage on Midland Railway.

† Owing to special nature of work there are three men in engine room and one for gas plant during hours of darkness.

95 arc lamps for street lighting, about 650 16-c.p. lamps, and about 38,000 8-c.p. lamps; it has been worked regularly without any other source of power to fall back on. It was due to the firm advocacy of gas power by the consulting engineer, Mr. J. Enright, that this useful and successful installation was made, and in Table B I give details of the working costs sent me by the electrical engineer in charge, Mr. F. A. Wilkinson :—

TABLE B.—WALTHAMSTOW.

Returns for one year ending 31st March, 1903.

Total B.T. units generated, 659,796.
Load factor, 15·25.
Average fuel consumption, 2 lbs. per unit generated, including all stand-by and other losses.
Works cost per unit generated :—

*Coal and other fuel...	0·34	penny.
Oil, waste, water, etc.	0·19	„
†Wages for generation	0·33	„
Repairs and maintenance of gas plant, engines and electrical plant	0·03	„
Total	0·89	„

In addition to the above I give the following extracts from Mr. Enright's official report :—

"*Test No.* 1, *April* 10, 1902.—Test of two gas engines operated by one gas generator, time 4 hours. In this test a consumption of 832 lbs. of fuel produced 588 B.T. units, equal to 1·41 lbs. per unit, or nearly as possible 1 lb. of coal per H.P. hour.

"*Test No.* 2, *April* 25, 1902.—Test of three engines at full load with two gas generators not at full load, time 3½ hours. This test showed a consumption of 1·52 lb. of coal per unit, which is slightly in excess of that obtained in test No. 1, no doubt due to the gas generators not being worked at full load.

"*Test No.* 3, *April* 26, 1902.—Four engines at full load with two gas generators, also at full load, time 4 hours. The four sets during the four hours generated 1,094 units with fuel consumption 1,456 lbs., which worked out to 1·33 lbs. per unit, or slightly less than 1 lb. per H.P. hour.

"I have satisfied myself that at full load the coal consumption of these engines is as nearly as possible 1 lb. per H.P. hour under the conditions prevailing in an electric light station."

3. *Smallheath.*—This installation is at the works of the Birmingham Small Arms Co. They use Dowson gas-power for over 1,500 H.P., and about two-thirds are for electric lighting and electric power. I have not any returns for the whole installation, but I am able to give the results of a careful test with a 250 B.H.P. Westinghouse engine and dynamo, made at these works by the consulting engineer, Mr. Henry

* Coal cost average of 26s. per ton delivered.
† One man for two eight-hour shifts, and two men for remaining eight-hour shift.

Lea of Birmingham. The trial lasted five consecutive days, and the following were the results :—

TABLE C.—SMALLHEATH.

Total B.T. units generated, 6,339.

Average calorific power of gas (by calorimeter), 166 B.T.U. at 0° C. and 760 mm. (steam condensed).

Number of working hours during trial, 42¾.

Number of standing hours during trial, 62¼.

Total fuel consumed, including banking fire and all other sources of waste, = 12,214 lbs. = 1·93 lbs. per B.T. unit generated.

Fuel consumed per standing hour = 4½ lbs.

Total water consumed in gas plant = 1 gallon per B.T. unit generated.

(Gas made from small anthracite peas costing 20s. 6d. per ton delivered).

4. *Limerick.*—This is a small central station belonging to the Corporation of Limerick, and there are three sets of engines and dynamos of 75 kilowatts each, with two gas generators of 225 B.H.P. each. The engines and dynamos are direct coupled and are of the Westinghouse make. A recent test of two engines and one gas generator by the consulting engineer, Mr. Enright, gave the following results :—

Consumption of anthracite peas in gas generator and coke in boiler = 1·3 lbs. per B.T. unit generated, exclusive of stand-by, etc., losses.

Consumption of anthracite in gas generator while standing 3·8 lbs. per hour.

SUCTION PLANT.

In the foregoing examples the gas producer is worked with a jet of superheated steam, which injects the air required for combustion of the fuel. The steam required is produced in a small vertical boiler, and the gas made is passed into a gasholder for distribution. A new type of plant is now coming into favour, in which the boiler and gasholder are dispensed with, and for installations of moderate size it has certain obvious advantages. Fig. 1 shows a set of this plant for 40 B.H.P. which I have tested in connection with a National gas engine of the same power, and the following results were obtained in a twelve hours' run :—

Average calorific power of gas produced during the first six hours 143 B.T.U. and during the last six hours 152 B.T.U. per c. ft. at standard temperature and pressure.

Average composition of gas produced :—

	During first six hours.	During last six hours.
Carbon monoxide, CO ...	22·5	23·7 per cent. by volume
Carbon dioxide, CO_2 ...	6·1	6·3 ,, ,,
Oxygen	0·5	0·5 ,, ,,
Hydrogen	14·5	15·6 ,, ,,
Marsh gas, CH_4	1·3	1·4 ,, ,,
Nitrogen	55·1	52·5 ,, ,,

Average I.H.P. 47; average B.H.P. 40.

Total fuel consumed in 12 hours = 397 lbs. = 33·1 lbs. per hour = 0·82 lbs. per B.H.P. = 0·70 lbs. per I.H.P.

Water consumed in gas plant = 33 gallons per hour = 0·8 gallons per B.H.P. per hour.

As the volume of gas produced could not be measured while the plant was being worked by the suction of the engine, a separate test was made with a suction fan to draw air into the producer, instead of the engine. The gas produced was then passed into a gasholder, and its rate of production determined: the heat efficiency of the plant was then found to be about 90 per cent. For this test the calorific power of small anthracite peas (by calorimeter) was 12,600 B.T.U.; as this power was low it was confirmed by further tests, and may be taken as correct.

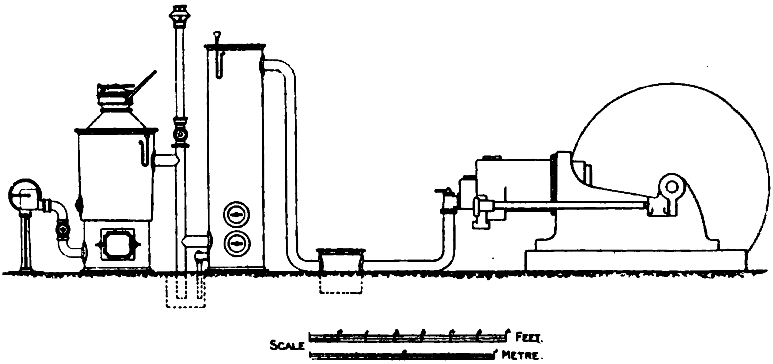

FIG. 1.—Dowson Suction Plant and National Engine for 40 B.H.P.

This plant has since been tested with small gas coke, and during a run of 8 hours the average calorific power of the gas was 143 B.T.U., while the consumption of coke was about 15 per cent. more than with anthracite.

The producer contains about three hours' supply of fuel, and the attendance of one man for about two hours each day is sufficient. The engine can be started in fifteen minutes after lighting the fire in the gas producer.

FUEL PER UNIT GENERATED.

The examples I have given are typical for various sizes, and I have summarised the results in the following table :—

TABLE D.

Locality.	Average fuel consumption per unit generated, including stand-by and all other losses.
Leicester ...	3 lb. average for five months (January to May, 1903).
Walthamstow	2 lb. „ „ one year ending March 31, 1903.
Smallheath ...	1·93 lb. „ „ five days' test.

At Walthamstow the fuel cost about 26s. per ton delivered, and yet the cost per unit was only 0·34d.

At Leicester it cost 15s. per ton, exclusive of carriage over the Midland Railway, and the cost per unit averaged 0·245d. At the same time it should be noted that the fuel consumed at Leicester was 3 lbs., while that at Wathamstow was only 2 lbs. per unit, and doubtless the higher consumption at the former place is due partly to the exceptional load factor and partly to smaller units being used.

Stand-by Losses.

Quite apart from the fuel consumed per H.P. while the plant is working, I think it is important to consider separately the fuel consumption during the stand-by hours.

Concerning *Leicester*, Mr. Deeley, the Locomotive Superintendent of the Midland Railway, writes as follows:—

"A 24 hours' trial has been made at Leicester, and it is found that the amount of coal required to leave the generator [150 H.P.] in the same state at the end of the 24 hours, as it was at the beginning, was 51 lbs., or 2·1 lb. per hour, and at the end of this period gas was passed into the gasholder (ready for use) in ten minutes. A steam boiler of the same H.P. under the same conditions requires 14 lbs. of coal per hour to maintain its pressure ready for immediate use."

From *Walthamstow* Mr. Wilkinson, the electrical engineer, writes: "I have made some tests on the gas generators installed at these works, to ascertain the actual consumption of anthracite in a gas generator when standing with a fire in it and when gas was not being made. The 375 B.H.P. generator was standing 48 hours, and the total weight of coal consumed was 84 lbs." This is equal to only 1·8 lbs. per standing hour.

At *Smallheath* a producer of 250 B.H.P. max. consumed 4½ lbs. of anthracite peas per standing hour; at *Limerick* a 225-B.H.P. producer consumed 3·8 lbs. per hour. I could give other cases, but doubtless these will suffice as they are authentic and independent. The general result is that with producers ranging from 150 to 375 B.H.P. each, the average consumption during the stand-by hours is only 3 lbs. per hour.

To compare the stand-by consumption of a steam boiler with that of a gas producer, it is obviously desirable to have the returns for individual boilers, and although I sought this information from several well-known quarters I found that no one could give me exactly the information I wanted. However, I interested some engineers in the subject, and they were good enough to have special tests made. The following are notes of the information sent me:—

Professor Kennedy kindly looked into the matter and wrote: "What I have repeatedly measured is the proportion borne by the coal actually used at a generating station, in boilers of which the stop-valves are closed, to the total coal used in the same time in the station. I have found that during the heavy hours of working in an electric lighting station, *i.e.* from 3 to 11 p.m., this proportion is about 2½ per cent. Measured over the whole 24 hours' load in one case I found it to amount to 7·2 per cent.

for a fortnight, in another case 7·8 per cent. At other times over 48 or 72 hours, I have found it to average 10 per cent. All these higher figures are for cases where a very large number of boilers have to be kept or got ready for a very short peak." This information, although interesting in itself, does not enable us to arrive at the stand-by loss of an individual boiler.

Colonel Crompton has sent me the following report from one of his staff at Chelmsford: "Although we have never made a special test for the particular purpose in question, we have found that to keep up one of our hand-fired Babcock & Willcox boilers hot and ready for steam at short notice during a period of about 10 hours required about 6 cwts. of hard steam coal, or thereabouts. Under the above conditions the boiler would be coupled to the main steam range, *i.e.* not isolated. The rating of the boiler is 4,200 lbs. per hour, and the coal used is Shipley best hards.

"I called at the Chelmsford Electric Light Co.'s Station to see if I could obtain any figures on the subject, as they practically always have one boiler banked up during the day, and they tell me that they use about 3 cwts. on a similar boiler to ours, but with chain grate stoker, and under similar conditions during about 10 hours it took another 3 cwts. to make the boiler begin to generate steam. The coal used in this case would be Shipley Peas."

In both these cases the consumption = 67 lbs. per standing hour.

Mr. Henry Lea of Birmingham has had a special test made, and has kindly sent me the following particulars:—

Lancashire boiler 28 ft. long × 7 ft. 6 in. diameter with two flues, each 3 ft. diameter. Evaporative power in full work 8,000 to 9,000 lbs. of water per hour. Consumption of Cannock screened coal in boiler while standing 12 hours, about 4 cwts. During this time the steam pressure fell from 120 lbs. to 90 lbs., and it was not raised again to 120 lbs. Consumption while standing = 37½ lbs. per hour.

Mr. F. A. Wilkinson, engineer to the Urban District Council of Walthamstow, has had a special test made and sends the following:—

Lancashire boiler (Galloway) 30 ft. long by 9 ft. diameter, grate area 47½ square feet. This boiler was one of a battery: on one side there was a similar boiler doing regular work, and on the other side a similar boiler which had been shut down for some months. The fires were cleaned just before the start and end of test. There was a Musgrave superheater at end of boiler. The valve between the range and the superheater was closed. There was a slight leakage at the deadweight valve throughout the test, and a certain amount of water escaped through the trap which drains the superheater connections. The water in gauge glass fell ¾ in. during trial. Consumption of coal during twelve hours' standing 537 lbs. = 44·7 lbs. per hour.

Mr. H. Collings Bishop, borough electrical engineer of Newport, Mon., has made two special tests, and sends the following particulars:—

Trial 1.—Two Babcock & Willcox boilers of 500 H.P. each. Consumption of Welsh coal (colliery screenings) during five hours standing, 1,800 lbs. Steam pressure at start 120 lbs. dropped to 80 lbs.

while standing, and raised to 120 lbs. at finish. Consumption = 180 lbs. per boiler per hour.

Trial 2.—Same boilers (week end) consumed while standing twenty-nine hours 6,500 lbs. Steam pressure at start 120 lbs. fell to 50 lbs. and raised to 120 lbs. at finish. Consumption = 112 lbs. per boiler per hour.

Messrs. Willans & Robinson have also made a special test and give the following result:—

Niclausse type of boiler capable of evaporating 8,000 lbs. of water per hour; dimensions 13 feet by 10 feet by 10 feet high. Consumption of Midland large coal 600 lbs. while standing twelve hours, full steam pressure and water level maintained throughout the trial. Consumption = 50 lbs. per hour.

I give a résumé of these results in the following table, and in estimating the maximum H.P. of the boilers I have allowed 20 lbs. of water per H.P. per hour.

TABLE E.—CONSUMPTION OF FUEL IN STAND-BY HOURS.

Gas Power.			Steam Power.		
Locality.	Max. H.P. of Producer.	Consumption per hour. Pounds.	Type of Boiler.	Max. H.P of Boiler.	Consumption per hour. Pounds.
Leicester ...	150	2·1	Various	150	14·0
Walthamstow	375	1·8	Babcock & Willcox	210	67·0
Smallheath ...	250	4·5	Babcock & Willcox	210	67·0
Limerick ...	225	3·8	Lancashire	450	37·3*
			„	400	44·7
			Babcock & Willcox	500	180·0
			Babcock & Willcox	500	112·0
			Niclausse	400	50·0
	Average	3·0		Average	71·5

* Exclusive of raising steam from 90 to 120 lbs.

It is clear that the stand-by loss in a gas-producer is trifling compared with that of a steam boiler of any type, and the explanation is not far to seek. The producer is much smaller in size, and has a much smaller radiating surface than a boiler of the same H.P., it has a thick lining of firebrick which is kept warm by the fire left in it, there is no water in it, and it can be worked up to its maximum production of gas in about fifteen minutes after standing almost any length of time. With a boiler there is a large amount of external brickwork to be heated, and there is a considerable quantity of water, even in the tubular type. Doubtless the heat efficiency of a good boiler is high, when it is working to nearly its full capacity, but the reverse is the case when it is standing, and I think that in factories and electric

light and power stations, where the plant is usually standing a long time, this question deserves closer attention than it generally receives, especially where the power required involves several boilers.

KIND OF FUEL TO BE USED.

Apart from the weight of fuel required for a given power, it is important to consider the kind of fuel, chiefly in relation to the cost of making suitable gas. When I first started working a gas engine with a gas plant some twenty-five years ago the largest engine then made developed under 20 B.H.P., and for various reasons I had to wait several years before engines of 50 and 100 H.P. came into use. As the fuel consumption was not much over 1 lb. per H.P. per hour, the total fuel required was comparatively small, and the mere cost of the fuel per ton was less important than the certainty of not having tarry gas, especially in the days of slide valves. I therefore worked with anthracite coal or gas coke, and even now it is best to do so for small powers, or for large powers where bituminous coal costs nearly as much as anthracite peas or small coke. It is also worth remembering that the use of bituminous coal involves a much larger scrubbing plant, so that the first cost is higher, and it needs more ground space and more labour. At the same time it is quite right to use bituminous coal where an appreciable saving can be made by using it, and where it is suitable in other respects. For several years I have been trying various methods of making good clean gas on a practical scale with bituminous coal, but I have only recently satisfied myself that the results were good enough, on the lines I thought it right to follow. I consider it wrong to let the gas leave the producer highly charged with tarry vapours, and then to remove the tar by scrubbing, etc., as it not only leads to waste of some of the most valuable heatgiving constituents of the coal, but it adds materially to the size and cost of the scrubbing plant, and to the difficulty of obtaining clean gas. What I have endeavoured to do, and what I have now succeeded in doing, is to decompose or partially oxidise practically all the tarry vapours in the producer itself, and I believe this to be right in principle and best in practice. Dr. Mond has produced his ingenious and well-thought-out recovery plant, but such a plant must be worked continuously, on a large scale, its first cost is great, the ground space required is considerable, and only certain kinds of coal can be used. A modification of this plant is now made without recovery of the ammonium sulphate, and in its main features it then resembles other well-known types of gas plants. As, however, I have a bituminous plant of my own, it would be invidious for me to attempt any comparison of their respective merits, and I only say that such plants can be obtained and used when it is desirable to have them.

I have heard it said that any kind of coal is good enough for a gas-producer, and with certain limitations this may be true for rough furnace work, where the tarry gas produced is taken direct to the combustion chamber of the furnace. But for engine work there must be a better selection of the coal, it should not be of the caking kind,

and a poor, dirty coal will be dearer to use than a good coal, if it has to be carried far, the cost of carriage being the same in either case, and being often greater than the cost of the coal itself. In considering the possible economy to be effected with bituminous coal in a gas plant, its calorific value as well as its other qualities should be taken account of. For instance, the calorific power of anthracite of average quality is about 14,000 B.T.U. per pound, and sometimes it is nearly 15,000. Coke of average quality has about 13,000 B.T.U., but it varies considerably in different localities, owing to the various qualities of coal from which it is derived. In both these fuels the fixed carbon is usually from 80 to 90 per cent. In most of the bituminous coals suitable for gas plants the fixed carbon is only about 50 to 60 per cent., while the volatile constituents vary from about 20 to 30 per cent., and if the bulk of these hydrocarbons are allowed to be distilled off in condensable vapours, it follows that the loss must be considerable. It is therefore important to consider not only the calorific power of the coal, but its suitability for the type of producer in which it is to be converted. It is not so simple as selecting a suitable coal for firing a steam boiler.

Heat Efficiency.

It is instructive to compare the possible and actual heat efficiencies of a gas-power plant with those of a steam-power plant, and I will endeavour to do this as briefly as I can. For steam boilers I have consulted the late Mr. Bryan Donkin's work on the Heat Efficiency of Steam Boilers. He gives the results of a large number of careful tests, and they show the following averages :—

Description of Boiler.	No. of Boilers Tested.	Average Heat Efficiency.
Water tube (Babcock & Willcox type)	16	61·2 per cent.
Lancashire	161	63·4 "
Water tube (various types) ...	27	67·5 "
Cornish	37	67·6 "
Marine	32	69·0 "
Locomotive and Portable ...	36	72·4 "

The last named are seldom used for stationary engines, and strictly speaking they should not be included.

In his interesting lecture at the Royal Institution (1893) Professor Kennedy dealt with the relative efficiencies of steam and gas engines, and he pointed out that the amount of heat actually taken up by the steam in an ordinary boiler varies from 50 to 80 per cent. of the whole heat energy of the fuel. "The 50 per cent. is the result of every-day careless working, the 80 per cent. the result of thoroughly good working with real care." Then as to the steam engine, he explained that its theoretical maximum efficiency is only 30 per cent., and that actually "only 5 to perhaps 15 per cent. of the whole heat of the steam is ever

turned into work, sometimes a little more, more often a little less." He further pointed out that the waste of heat due to condensation in steam pipes, the driving of feed pumps and other inevitable losses, usually represents about 10 per cent. of the total heat of combustion. Then turning to the gas engine he showed that its theoretical efficiency is about 80 per cent., and that the actual energy utilised is about 26 to 30 per cent. of the total heat developed in the cylinder.

I will now give the results of some careful tests I have had made with gas plants of my own design.

Test A.—40 B.H.P. plant (at Basingstoke) with air injected by a jet of superheated steam from boiler.

One kilo of anthracite peas gasified in the producer yielded 5·04 cubic meters of gas at 0° C. and 760 mm. The corresponding consumption of ordinary gas coke in the little boiler was 0·18 kilo. The composition of the gas was as follows:—

Carbon monoxide, CO	23·8	per cent. by volume.
Carbon dioxide, CO_2	6·3	" " " "
Hydrogen	19·8	" " " "
Marsh gas, CH_4	1·3	" " " "
Nitrogen	48·8	" " " "
	100·0	

The calorific power of the gas, calculated from the above analysis, is 1,463 calories per cubic metre at standard temperature and pressure. The balance-sheet of heat units is as under:—

	Calories.		*Calories.*
1 kilo anthracite (by calorimeter)	8,200	5·04 cubic metres of gas at 1,463 cals. per cm. ...	7,370
0·18 kilo coke (by calorimeter) at 7,200 cals. per kilo ...	1,300	Heat lost in process ...	2,130
Total heat in fuel ...	9,500		9,500

$$\text{Efficiency of gas plant} = \frac{7,370}{9,500} = 0·776 = 77·6 \text{ per cent.}$$

In British thermal units the results are as under:—

One pound of anthracite gasified in producer and 0·18 lbs. coke in boiler yielded 80·9 cubic feet of gas (at 32° F. and 29·9 inches mercury pressure), having a calorific power of 164 B.T.U. per cubic foot. The balance-sheet of heat units is as follows:—

	B.T. Units.		*B.T. Units.*
1 lb. anthracite	14,760	80·9 cubic feet of gas at 164 units per cubic foot ...	13,270
0·18 lb. coke at 12,960 units per lb.	2,330	Heat lost in process ...	3,820
Total heat in fuel ...	17,090		17,090

$$\text{Efficiency of gas plant} = \frac{13,279}{17,090} = 0·776 = 77·6 \text{ per cent.}$$

Test B.—250 B.H.P. plant (at Openshaw) with air injected by jet of superheated steam from boiler. This plant has been working regularly over fifteen years, and the test was made four years ago, while it was working in the usual way.

One kilo of anthracite nuts gasified in generator yielded 4·88 cubic meters of gas at 0° C. and 760 mm. The corresponding consumption of ordinary gas coke in the boiler was 0·14 kilo. The composition of the gas was as follows:—

Carbon monoxide, CO	... 26·5	per cent.	by volume.
Carbon dioxide, CO_2	... 4·4	"	"
Hydrogen	... 17·5	"	"
Marsh gas, CH_4	... 2·1	"	"
Nitrogen	... 49·5	"	"

The calorific power of the gas by calculation and the average by calorimeter is 1,552 calories per cubic metre at standard temperature and pressure. The balance-sheet of heat units is as under:—

	Calories.		*Calories.*
1 kilo anthracite (by calorimeter)	8,200	4·88 cubic metres of gas at 1,552 cals. per cm. ...	7,570
0·14 kilo coke (by calorimeter) at 7,200 cals. per kilo ...	1,000	Heat lost in process ...	1,630
Total heat in fuel ...	9,200		9,200

$$\text{Efficiency of gas plant} = \frac{7{,}570}{9{,}200} = 0·823 = 82·3 \text{ per cent.}$$

In British thermal units the results are as follows:—

One pound of anthracite gasified in producer and 0·14 lbs. coke in boiler yielded 78·3 cubic feet of gas (at standard temperature and pressure) having a calorific power of 175 B.T.U. per cubic foot. The balance-sheet of heat units is as follows:—

	B.T. Units.		*B.T. Units.*
1 lb. anthracite	14,760	78·3 cubic feet of gas at 175 units per cubic foot	13,700
0·14 lbs. coke at 12,960 units per lb.	1,810	Heat lost in process ...	2,870
Total heat in fuel ...	16,570		16,570

$$\text{Efficiency of gas plant} = \frac{13{,}700}{16{,}570} = 0·827 = 82·7 \text{ per cent.}$$

Test C.—250 B.H.P. plant (at Smallheath) with air injected by jet of superheated steam from boiler.

One kilo of anthracite peas gasified in generator yielded 4·37 cubic metres of gas, at 0° C. and 760 mm. The corresponding consumption of gas coke in the boiler was 0·10 kilo.

The calorific power of the gas by calorimeter is 1,477 calories per cubic metre (= 166 B.T.U. per cubic foot), at standard temperature and pressure. The balance-sheet of heat units is as under :—

	Calories.		*Calories.*
1 kilo anthracite (estimated)	8,000	4·37 cubic metres of gas at 1,477 cals. per cm. ...	6,454
0·10 kilo coke at 7,000 cals. per kilo (estimated) ...	700	Heat lost in process ...	2,246
Total heat in fuel ...	8,700		8,700

$$\text{Efficiency of gas plant} = \frac{6{,}454}{8{,}700} = 0{\cdot}742 = 74{\cdot}2 \text{ per cent.}$$

In British thermal units the results are as follows :—

One pound of anthracite gasified in producer and 0·10 lb. coke in boiler yielded 70 cubic feet of gas (at standard temperature and pressure) having a calorific power of 166 B.T.U. per cubic foot. The balance-sheet of heat units is as follows :—

	B.T. Units.		*B.T. Units.*
1 lb. anthracite (estimated)	14,400	70 cubic feet of gas at 166 units per cubic foot ...	11,620
0·10 lb. coke at 12,600 units per lb. (estimated) ...	1,260	Heat lost in process ...	4,040
Total heat in fuel ...	15,660		15,660

$$\text{Efficiency of gas plant} = \frac{11{,}620}{15{,}660} = 0{\cdot}742 = 74{\cdot}2 \text{ per cent.}$$

To illustrate further these heat efficiencies, and to compare gas with steam power, I would refer to the diagrams shown in Figs. 2, 3 and 4. The first is for steam power, and for the boiler I have assumed an efficiency of 80 per cent., although Mr. Bryan Donkin's averages give a mean of about 67 per cent. including those of the locomotive and portable type; but to be on the safe side, I have taken what Prof. Kennedy says can be got with thoroughly good working. For the steam engine I have assumed a heat efficiency of 15 per cent., and for the sundry losses named by Prof. Kennedy I have taken his allowance of 10 per cent. of the total heat energy of the fuel consumed. This diagram may not be strictly accurate—I believe it is more favourable than average working would give—but it is near enough for the purpose of a general comparison.

As far as possible Fig. 3 is based on the trials made at Smallheath, of which I have already given details. The heat units in the fuel actually consumed in the gas plant, as well as those in the gas required to produce 100 I.H.P., are known, and from the latter the heat efficiency of the engine is known to be 28·5 per cent. The loss of 71·5 per cent. of the heat supplied to the engine is divided between the exhaust and the cooling water, $\frac{5}{8}$ths being attributed to the former, and $\frac{3}{8}$ths to the

latter. Even if the last two sources of loss are incorrectly estimated, the 71·5 per cent. is correct, and the general result will not be affected, as it was proved in the trials that with a certain consumption of fuel there was a certain production of power (measured electrically). I should have preferred to include all the stand-by losses in both these diagrams, but although I know that it was only 4½ lbs. per hour for the gas plant, I don't know what it would have been with the steam plant, and therefore I have left it out in both diagrams. At the same time, we may safely conclude that it would have been much greater for the

STEAM POWER—250 B.H.P.

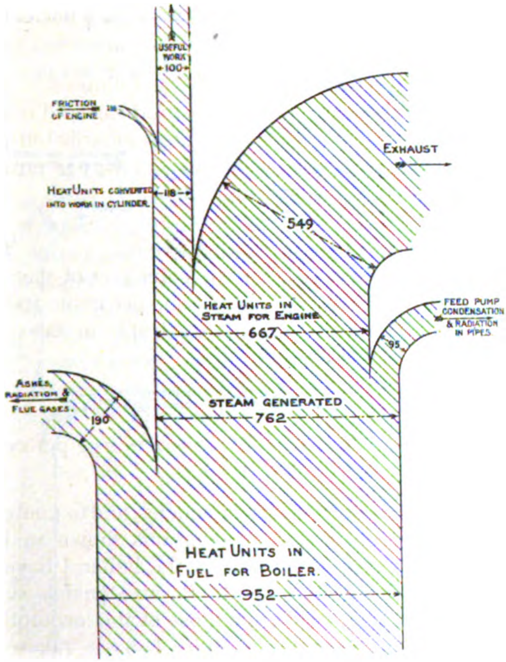

FIG. 2.—Heat Diagram based on Boiler efficiency 80 per cent. and Engine efficiency 15 per cent., as detailed page 356.

steam power than for the gas power. The friction of the engine is taken at 15 per cent. of the I.H.P.

Finally, in Fig. 4 I have taken the actual results of the trial of a suction plant with a 40 B.H.P. National engine referred to on page 347, and in this case I have assumed the same relative percentage of loss for the cooling and exhaust of engine as in Fig. 3. I think it will be allowed that for such a small power the result is very satisfactory.

POSSIBLE HEAT EFFICIENCIES OF GAS AND STEAM POWER.

The diagrams I have described represent what has actually been achieved, and before leaving the subject I would add a few words as

to possible results in the future. It seems to me unlikely that the actual heat efficiency of a steam boiler, under the best conditions, can be much above 80 per cent.; but for the moment let us assume that it may possibly reach 90 per cent., exclusive of stand-by losses, feed pumps, condensation in pipes, etc. The heat efficiency of a 250 H.P. gas plant which has worked many years, has been shown to be 82·3 per cent., including a separate boiler for serving the producer with steam. If the steam had been raised by the waste heat of the producer, and the

GAS POWER — 250 B.H.P.

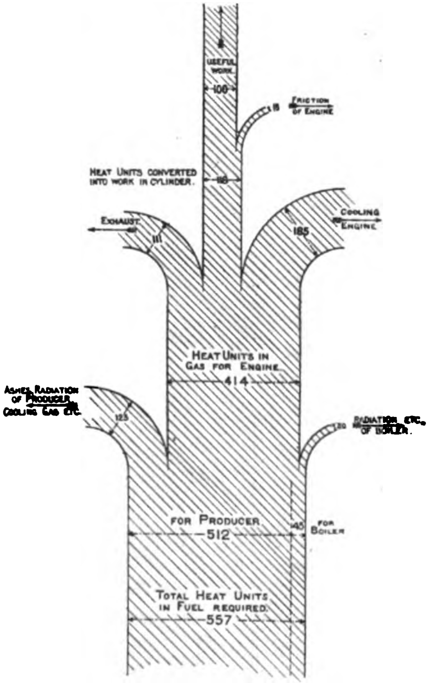

Fig. 3.—Heat Diagram based on Trials at Small Heath, as detailed page 356.

GAS POWER — 40 B.H.P.

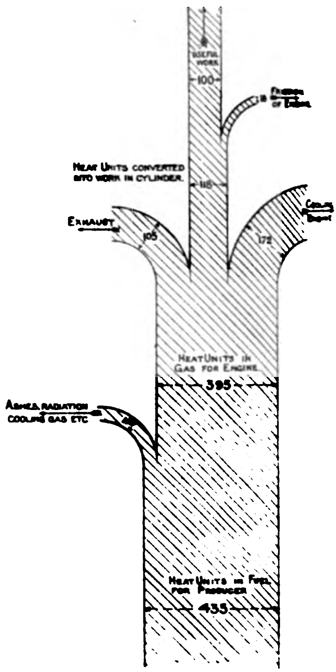

Fig. 4.—Heat Diagram based on Trials of Suction Plant and Engine, as detailed page 357.

hot gases which leave it, as in the suction type of plant, the efficiency would have been 92·5 per cent. without any deduction being necessary for pumps, condensation, etc., while the stand-by loss is trifling. We have seen that even with a small 40-H.P. suction plant it is actually about 90 per cent. It is therefore safe to assume that with further perfections the heat efficiency of the gas plant doing actual work will be higher than that of the steam boiler and accessories. Then as to the steam engine, Prof. Kennedy tells us that "its theoretical maximum efficiency is only 30 per cent.", whereas that of the gas engine is "about 80 per cent." We see, therefore, that although good results have already been

obtained with gas power, there are much greater possibilities of improvement with it than with steam power, especially as regards the engine, and one is encouraged to think that it will do better still in course of time, when the present great losses in cooling and in the exhaust have been minimised.

In this connection, I believe that Dr. Mond has suggested the use of the engine exhaust for raising the steam required for his gas producer. It may be a move in the right direction, but an ordinary producer plant (without recovery of ammonium sulphate) does not need more steam than the heat from the producer and from the gas can produce. My own suggestion has been that the air for the producer should be heated by the engine exhaust, but it would not be worth while to do this for any power under 100 B.H.P. or where the load on the engine was not fairly constant. If the hot air produced were not used for the producer, it could be used for warming workrooms in a factory, etc.

Conclusion.

I have referred to the considerable saving in water with gas power, to the moderate cost of repairs and maintenance, and I have dwelt on the saving in fuel not only in the working but in the stand-by hours. These are its chief recommendations, and I think they are of sufficient importance to claim your attention. Even where it may not be desirable or possible to have a complete gas-power installation, it may be advantageous to have gas power for the peak of the load. There would then be less stand-by loss in the boilers, and they would be worked under fuller and more constant loads than is now often the case. The gas power would be the auxiliary for the top of the load and for emergencies.

NOTICE.

1. The Institution's Library is open to members of all Scientific Bodies, and (on application to the Secretary) to the Public generally.

2. The Library is open (except from the 14th August to the 16th September) daily between the hours of 10.0 a.m. and 6.30 p.m., except on Saturdays, when it closes at 2.0 p.m.

An Index, compiled by the late Librarian, to the first ten volumes of the Journal (years 1872-81), and an Index, compiled under the direction of the late Secretary, to the second ten volumes (years 1882-91), can be had on application to the Secretary, or to Messrs. E. and F. N. Spon, Ltd., 125, Strand, W.C. Price Two Shillings and Sixpence each.

A further Index, compiled by the Secretary, for the third ten volumes (years 1892–1901) is now ready, price Two Shillings and Sixpence, and may be had either from the Secretary or from Messrs. Spon.

Publishers' Cases for binding Vol. 32 of the Journal can now be had from the Secretary or from Messrs. Spon, price 1s. 6d. each.

JOURNAL

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Institution of Electrical Engineers.

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The Four Hundred and Third Ordinary General Meeting of the Institution was held at the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, February 11, 1904—Mr. ROBERT KAYE GRAY, President, in the chair.

The PRESIDENT: Gentlemen, before we begin the business of the evening, by the wish of the Council I have to tell you that Mr. McMillan died on the 31st of January. You are doubtless aware of the fact through the notices which have appeared in the press, but as this is our first meeting since the sad event, it is only right that a few remarks should be made on the subject. I have no intention of saying to you, who knew Mr. McMillan so well, what his qualities were. We shall all miss him. I only wish to state that he has left behind him a widow and two children. Unfortunately, as our constitution is framed, neither the Council nor the Institution is able to deal with the matter from a financial point of view as we would like to do; and therefore to-day, at the first ordinary Council meeting held since Mr. McMillan's death, it was decided that the Council would invite the members of the Institution to assist, so far as they can, those Mr. McMillan has left behind. The Council has done everything in other directions that could be done. Sir Henry Mance, Dr. Swan, Dr. Thompson, Mr. Patchell, and our late Secretary, Mr. Webb, went to Golder's Green to the funeral; the rest of the Council, all those who were able to go, were present at the service at Streatham. Gentlemen, I have nothing further to say, but as you would doubtless like to express to Mrs. McMillan the sympathy you feel with her in her great loss, which, I am sorry to say, has been followed by the death of her mother, I will ask Sir Henry Mance, who was President when Mr. The President.

The President. McMillan was elected Secretary, to move a resolution, and I will ask the available Past-President who was last in office preceding me to second it.

Sir Henry Mance. Sir HENRY MANCE: Mr. President and gentlemen,—The resolution which has been entrusted to me is one, I am sure, that will meet with sympathy from all of you, for there are few men who have enjoyed the respect of their fellow men to a greater extent than our late Secretary, Mr. McMillan. While listening to our President's remarks, it came home to me that, as we grow older, time seems to fly past us with greater and greater rapidity with every additional year. I can hardly realise the fact that it was six or seven years ago that I had, as President, the honour of presiding at your Council which met to decide on a successor to our old friend Mr. Webb. I can bear testimony to the impartiality and the care that was exercised by the Council on that occasion, and time and experience have shown the wisdom of their choice. I think if Mr. McMillan had one fault it was that of extreme devotion to duty and to the care of the interests which were entrusted to him. As an administrator he endeavoured faithfully and diligently to carry out to a practical and successful conclusion the wishes of his Council. He exercised in the performance of his duty the utmost tact and amiability, and I think every Past-President or member of the Council will agree with me that it was a pleasure to work with him. I am not desirous of detaining you with more than the briefest remarks; I will simply say that while the Institution has lost a most valuable official we have also all of us lost a personal friend. The resolution which I have to submit is as follows: "That the members of the Institution of Electrical Engineers in full meeting desire to express their profound sorrow at the death of their late Secretary, Mr. Walter George McMillan, and to put on record their high appreciation of his personal character and of those qualities which, as a scientific man and an administrator, have contributed so much to the prosperity of the Institution, and also to express to Mrs. McMillan and other members of the family their heartfelt sympathy under this sad calamity."

Prof. Perry. Prof. J. PERRY: Mr. President and gentlemen,—I have the honour to second this resolution. It did not need the eloquent words of Sir Henry Mance, it needs no words from me, to ensure your recognition of the great loss we have sustained. The loss to the Institution is of enormous importance, but there is also the loss that each of us personally feels, the loss of a kindly sympathetic friend. In our difficulties he was an adviser and helper, and many and many a one of us has come to him for advice and help, sure and certain to obtain it. I used to feel that by his mere character, through his mere presence and assured demeanour, he gave encouragement in right-doing and greatly discouraged wrong-doing and mean ways of thinking—and yet there might be no spoken words from him. I think we all feel that he did all that was possible for a man in his position, to set an example of Christian conduct before everybody who was privileged to meet him. But apart from this personal feeling there is not one of us who does not know that the Institution as a body has suffered a very great loss.

The members of Council and members of our numerous committees know it better than the ordinary members, but it is only the President and Past-Presidents who know this thoroughly. When, at the end of my year of office, I received the thanks of the Institution at the Annual General Meeting (May, 1901), I took occasion at some length to point out that I had been given credit for work which had been done altogether by Mr. McMillan. I spoke jocularly, and this is not a fitting occasion on which to quote the words which I used, but it might be worth the while of members to refer to what I said. Perhaps, however, you will allow me to quote the very end of my remarks on that occasion, for they now convey a sad meaning which did not then belong to them. After giving instances of the way in which Mr. McMillan had, with seeming ease, cleared away difficulties that had appeared to me very great, I said—"and I got the credit, but he was the man who did the work. But there is a serious side to this power of Mr. McMillan to take up all sorts of work and pull it through. We are taking too much work out of Mr. McMillan. There is a great deal too much output, and I am sorry to say that it is an output with too large a load factor. There is no interval of rest almost in the twenty-four hours. Until you become President of the Institution you do not really know how much work Mr. McMillan is doing." Now, gentlemen, I am sorry to think that when my year of office was over I had to work at many neglected things and did not attend meetings with regularity, but on several occasions I was struck with an appearance of "fag," of being "run down" in Mr. McMillan, and I feel sure that we allowed his zeal for the good of the Institution to overcome his discretion. It has been sudden, so sudden that many of us who would have desired to show our respect for his memory by going to his funeral were unable to do so. He was at that age when such a man is at his best, when his wife and family feel most assured of prosperous life; when a prosperous future has been earned by past sacrifices—and now it is all over, and his widow must mourn for him in a way so intense that all our mourning is nothing in comparison. But that mourning must be less grievous when she knows that her husband had earned the respect and gratitude of this great Institution, whose interests he had so much at heart. To her, therefore, and her two children and the other members of his family, it is most fitting that we send this message of condolence. Gentlemen, I have the honour to second this resolution. Prof. Perry.

The PRESIDENT: Gentlemen, it is quite unnecessary for me to put the resolution to you. I will communicate it to Mrs. McMillan. The President.

With regard to the fund that the Council will ask you to contribute to, we think we might get about £2,000. I am glad to say that a fund has been started by the press, and that any money that comes to that fund will be handed over to us in order that the Council may add it to the other subscriptions which we hope to receive. We shall now proceed with the ordinary business.

The Minutes of the Ordinary General Meeting held on Thursday, January 28, 1904, were by permission of the meeting taken as read and signed by the President.

The names of new candidates for election into the Institution were taken as read, and it was ordered that they should be suspended in the Library.

The following transfers were announced as having been approved by the Council :—

From the class of Associate Members to that of Members—

Walter James Bache.
Herbert H. Denton.
Reginald Sydney Downe.
Standen Leonard Pearce.
Edward John Wade.
Leicester William Woodman.

From the class of Associates to that of Associate Members—

Robert Donald Thain Alexander.
Herbert B. Johnson.
Herbert Tatlock Wilkinson.

From the class of Students to that of Associates—

George Bradwell.
J. M. de Artola.
T. A. Mitchell.
W. G. Perry.
H. W. Prance.
A. W. Pulvertaft.
A. L. Rawlings.

Messrs. C. J. Phillips and C. H. W. Biggs were appointed scrutineers of the ballot for the election of new members.

Donations to the *Library* were announced as having been received since the last meeting from Messrs. Macmillan & Co. and Professor S. P. Thompson; to the *Building Fund* from Messrs. R. H. Burnham, E. T. Caparn, A. D. Constable, P. A. Fisher, R. F. Fuller, V. W. Gill, W. Golledge, H. B. Graham, D. Henriques, T. E. Ingoldby, J. M. Smyth, H. D. Symons, L. C. B. Trimnell, A. D. Williamson, L. Wilson, and from the Volta Memorial Fund Committee; and to the *Benevolent Fund* from Messrs. D. Henriques and Sir H. C. Mance, to whom the thanks of the meeting were duly accorded.

The following paper was then read :—

TRANSATLANTIC ENGINEERING SCHOOLS AND ENGINEERING.

By R. MULLINEUX WALMSLEY, D.Sc., F.R.S.E., Member.

The subject which the writer desires to bring before the Institution to-night is one which, under different aspects, has attracted much attention in the engineering professions during the current year, and is in itself part of a much larger question. For some time there has been, in this country, a growing feeling of uneasiness that our methods of recruiting for both the higher and the lower ranks of engineering workers

have not shown themselves sufficiently plastic in following the changes caused by the ever-increasing applications of science and scientific methods to the solution of the more complex problems with which engineers are called upon to deal, and also in following the social changes which have specially affected the supply of skilled artisans for the factory and workshop. Further, the outcry that we are being beaten in our great staple industry of mechanical engineering—whether well founded or not need not be discussed here—has directed attention to the methods adopted in other countries to maintain the supply of directing managers, designers, and workers upon which a great measure of the success of the industry must depend, and interesting articles and papers on these methods have appeared from time to time. Mention need only be made of the two valuable papers read early last year by Prof. Dalby before the Institution of Naval Architects and the Institution of Mechanical Engineers respectively, and the important discussions thereon, and the discussion at the recent Engineering Conference introduced by a paper by Prof. Cormack on "Apprenticeship in Engineering Training."

The tour in the United States and Canada which has supplied most of the material for the present paper occupied three months, from March to June of last year, and was practically settled before the author heard that Prof. Dalby had recently been over part of the ground. Although he had the advantage of seeing a private preliminary report of the earlier tour before he started, the majority of the conclusions arrived at and stated herein were formed independently and before the writer had the advantage of reading the papers referred to above.

The tour itself arose out of the necessities of the educational work at the Northampton Institute, Clerkenwell. Three years ago pioneer day courses in mechanical and electrical engineering were started at the Institute, and early last winter the success of these courses raised the question of the permanent form to be given to them. It was matter of common knowledge that during the last ten or fifteen years large sums of money, running into many millions of pounds sterling, and derived from both public and private sources, had been spent in America on higher educational endowment and equipment, and that a large proportion of this money had been applied to engineering education. That something worth examining must have been brought into existence goes without saying. Further, the fact that matriculation examinations were being held in London by certain transatlantic institutions indicated that in the opinion of the authorities directing these institutions they were offering a better education than could be obtained here. Moreover, a broad review of the subject pointed to the conclusion that the methods adopted in the States and Canada were more likely to be applicable to this country than those in vogue on the continent of Europe. On several grounds, therefore, the Governing Body concluded that much valuable information could probably be gleaned in so promising a field, and the Principal was given the necessary leave of absence, and was instructed to investigate the methods of higher engineering education in the United States and

Canada, and more particularly the effect, so far as it could be ascertained, of this education on the engineering industries, the views of the great manufacturers and employers on the value of the products turned out by the schools, and the attitude generally taken up by them towards these schools.

Much of the ground to be covered was already familiar to the writer so far as such familiarity could be acquired from books, reports, and other publications, combined with a visit to the country about ten years previously. Nevertheless it was deemed advisable not to draw up the itinerary of the tour until after consultation with representative commercial men and educationalists in New York. The advantages of such a course in a land where, and at a time when, changes are so rapid, are obvious, more especially as one of the reasons for going at all was to investigate the supposed recent developments. The first few days in New York amply justified this plan, and yielded such valuable results that the period spent there was extended to nearly a fortnight. As a consequence the visit to other cities was commenced with a fund of information bearing on the problems to be investigated which could only be obtained by interviews with men who were in daily contact with these problems and had studied them under many and varied aspects. In addition New York itself and its vicinity, both during that first period and also at the end of the tour before re-embarking for England, offered a wide and rich field for investigation.

This preliminary investigation in New York also brought into prominence, sufficiently early to profoundly influence the whole course of the research, the conclusion that the most important part of the solution of the general problem was to be sought, not in the schools, but in the factories and amongst the captains of industry whose labours have produced such remarkable results in the commercial development of the United States during the last one or two decades. It was therefore decided to devote the greater part of the available time to this side of the problem, and with that end in view arrangements were made to visit more than one place in which there was no educational institutio to attract special attention. And, to economise time even in some o the cities on the route, institutions were not visited which by them selves were probably worthy of attention but which were to a gre extent replicas of others which had been or were to be inspected els where. Even when unvisited, however, such institutions were, as rule, carefully inquired about amongst representative local men ful acquainted with them. The necessity of weighing considerations li these shows the magnitude of the work contemplated and the re shortness of the time available for it, although at first sight that tim *i.e.*, three months in all, probably would appear to some more tha ample.

The places to visit having been settled, the itinerary eventua worked out was determined to a great extent by climatic consideratio Turning first southwards to Philadelphia, Baltimore, and Washingto it passed through Pennsylvania to Pittsburgh, then through Oh Indiana, and Illinois to Madison in Wisconsin. At this stage of t journey a hope that had been entertained in New York that it mig

be possible to penetrate further westwards had to be abandoned for want of time, and the course was therefore turned eastwards through Milwaukee to Chicago. Thence it was continued through Ann Arbor and Detroit to Buffalo, whence visits were made to Niagara and Toronto. From Buffalo the journey was continued through Rochester to Ithaca on Lake Cayuga, the seat of the well-known Cornell University with its Sibley College of Engineering, and thence the route was deflected northwards to Montreal for the purpose of visiting the McGill University, which has become so prominent in recent years. Returning southwards to Albany, a visit was paid to Schenectady, and then the New England States of Massachusetts, Rhode Island, and Connecticut, with their important educational and manufacturing centres, were examined as carefully as time permitted so as to leave a final week for New York and the cities within easy reach of it.

It will be noticed that this itinerary enabled the traveller to visit most of the important educational centres and many of the important manufacturing ones, with the exception of those west of the Mississippi and in the extreme south. Stops were made at the principal cities on the direct route, and from them were visited as many of the places within easy reach as the available time allowed. With these subsidiary journeys the whole distance travelled by rail amounted to nearly 5,000 miles, and altogether about 34 universities, colleges, and schools, and 48 factories were visited. In addition numerous interviews were held with business men at their offices not situated at the works. Lists of the schools and of the business, and the professional men other than those connected with the schools are given in Appendices A and B. Within the circuit of the itinerary these lists might have been considerably extended, but limitations of time, partly due to the desire to examine as thoroughly as possible the institutions and factories actually visited, made it impossible to do more. A selection, therefore, had to be made, governed in nearly every instance by some special reason. But it may fairly be claimed that no important educational institution within the itinerary and connected with higher engineering education was omitted, and that the business and professional men interviewed were thoroughly representative of the most important engineering industries. The conclusions arrived at below, whether valuable or not, are therefore based on data carefully collected from a wide and important field, and the writer ventures to hope that they may not be without interest and value to his fellow-members in the Institution of Electrical Engineers and to the English members of the profession generally.

It will perhaps be appropriate here for the writer to pause for a moment to testify to the great kindness with which he was received throughout the whole course of his investigations by all sorts and conditions of men. With very few exceptions indeed nothing could exceed the courtesy and assistance extended to him by busy captains of industry, by busy administrative officers, and by professional men, both educational and scientific. In the schools and in the factories, with scarcely an exception, everything he asked to see was shown to him

without reserve, and any statistics and information which he desired were placed at his disposal when available. Thus valuable data both scientific and educational were acquired, of which much is too voluminous to be included in, and some is outside the limits of the subject of, this paper, but all of which is of great interest and bears very directly upon the work carried on at the Northampton Institute. For all this, as well as for the generous hospitality extended to him from time to time, the writer desires to express his very cordial and sincere thanks.

To present the results obtained and the conclusions arrived at under the circumstances and conditions above described as concisely and conveniently as possible, the writer proposes to divide the subject as follows :—

(i.) The schools and their resources.
(ii.) The students available and the conditions of entrance.
(iii.) The work in the schools.
(iv.) The products and the attitude of employers.
(v.) The influence of these products on transatlantic engineering.
(vi.) Applications to Great Britain.

In the first five sections higher mechanical and electrical engineering education is mainly dealt with, to the practical exclusion of other branches of engineering education, to treat of any of which, however cursorily, even if the writer were competent for the task, would extend this paper beyond all reasonable limits. In section (vi.) an attempt will be made to draw a few lessons for home consumption. Originally the writer included with the above a section on the "training of bench hands, fitters and erectors," concerning which he made careful enquiries and accumulated a fair amount of material. The space, however, required for a not too full treatment of the other sections, which deal with the chief object of his tour, has compelled him to omit all reference to the cognate subject, the importance of which he does not underestimate. He may add in passsing that, in many respects, our arrangements here for the technical instruction and training of bench hands, etc., are better than the corresponding facilities provided in the United States and Canada.

I.—The Schools and their Resources.

Broadly speaking, the schools for higher engineering education in the United States and Canada may be divided into three classes :—

(*a*) Those attached to Universities which are not, either at all or to any great extent, supported by the State, but derive their funds from endowments, from private contributors and from students' fees. These Universities, as a rule, are much older than those in class (*b*). Columbia University, New York, the University of Pennsylvania, McGill University, Harvard University, and Yale University were the most representative ones visited. Cornell University, in the State of New York, occupies an inter-

mediate position between classes (*a*) and (*b*), but is more properly included in class (*a*).

(*b*) Those attached to the State Universities and almost, if not entirely, supported by the State in which they are situated and from federal funds. In these the fees charged to the students are small, and there are many free places. The most representative institutions of this class visited were the State Universities of Illinois, Wisconsin and Michigan, and Purdue University, Indiana.

(*c*) Those which are not attached to any University, but are frankly technological schools and nothing else; they are, as a rule, of private foundation, independent of State control, and derive a large proportion of their income from students' fees. Foremost among them stands the Massachusetts Institute of Technology, Boston. There were also visited the Stevens Institute of Technology, Hoboken, the Brooklyn Polytechnic, the Armour Institute and the Lewis Institute in Chicago, the Worcester Polytechnic, and others.

The institutions of the first section are found chiefly in the eastern or Atlantic States, those of the second are in the central and western States, whilst in the third class the institutions are scattered all over the country and are very numerous.

Resources.—The State aid of higher technical education in the United States dates from 1862, and the passing of the Morrill Act, by which a grant of public land was made to each State proportional to the number of Senators and Members of Congress which it returned to the Federal Legislature. The funds derived from this source, which in process of time have become large, are to be entirely spent upon the maintenance of the work and the payment of the instructors, and are not to be used for buildings or capital expenditure. A more recent Act passed in 1890 authorises the contribution of a further sum not exceeding £5,000 per annum to each State from the Federal Treasury, the amount contributed under this head in 1901 being £240,000.

The educational resources of these institutions may be most conveniently described under the heads of (1) buildings and land, (2) equipment, (3) staff, and (4) finance.

Buildings and Land.—Each of the Universities visited consisted of a series of fine buildings, often beautifully situated in extensive grounds belonging to the University. Amongst these the engineering building usually stands out very prominently, and most frequently the department of engineering has more than one building assigned to it. In many cases the position of the grounds has been selected with a keen eye for natural advantages. Nothing could exceed, for example, the beauty of the position of Cornell University, on a hill by the side of Lake Cayuga, or that of Madison University on the banks of a beautiful lake. Other Universities are scarcely less fortunate, and it may without exaggeration be said that students and professors work, in these favoured institutions, under ideal conditions as regards environment,

In regard to surroundings, the institutions in the third class, being most frequently situated in the centres of large cities, are not as a rule so well off, but they also are usually provided with large and commodious, and sometimes handsome buildings, carefully planned and well adapted for the work undertaken. The number and extent of the buildings devoted to higher engineering education exceeds anything that we can show in this country, as will be evident from the various statistics to be given later, but more often than otherwise the writer found that the supply of buildings was proving inadequate, and in many cases new engineering buildings were either being projected or were actually in process of erection or equipment. The architectural splendour of some of the buildings drew forth at times strong animadversions from native critics, but to these it may be replied that the money necessary for architectural adornment has been readily found, and that such buildings have an educational value outside the walls of the school, without taking account of the fact that in many cases a school of architecture is associated with the school of engineering.

Equipment.—When we turn to equipment we find still further evidence of lavish expenditure on a scale to which we are, as yet, unaccustomed in this country. The laboratories and workshops are packed full of apparatus and machinery for the use of the students. Dealing with workshops first, we may take as an example those of the University of Illinois, at Urbana. Here the engineering workshops are in a separate one-storey building which, with four other buildings, all devoted to engineering work, is erected behind "Engineering Hall," the main engineering building of the University. The fitting shop is about 100 ft. long and 50 ft. wide, and is fitted with twelve or fourteen good screw cutting lathes, a large 11 in. lathe with 27 ft. bed and a shorter lathe with a bed about 16 ft. long. In addition there are numerous milling and shaping machines, automatic tools and capstan lathes. There is in the same building a well-fitted foundry with a cupola and a forge containing twenty hearths, with a power blast and an exhaust fan taking the smoke from each hearth, and also a small steam hammer. The carpenters' and pattern makers' shop is in another building devoted entirely to woodworking. It consists of two large rooms with a wide open corridor and offices between. These rooms are well fitted with hand tools and benches, as well as power-driven lathes and other woodworking machines. It should not be overlooked that this is the workshop equipment of a *University* Department of Engineering.

As another example, this time drawn from a technical institute, may be cited the "Machinery Hall" of the Armour Institute, a separate building of four floors with a basement for storage, office accommodation and heating and ventilating apparatus. The foundry, placed on the top floor, has working space for about twenty students, a 1½-ton cupola, a core oven, an air-compressor for working chipping chisels, and a small class-room fitted with a moulding table. On the floor below is the woodworking shop with working benches for thirty-six students, and an equal number of small lathes; also two large lathes, two band saws and other machine tools. On this floor also there is a class-room fitted with a working bench and a lathe for

the lecturer or demonstrator. Next below this is the fitting shop, fitted with hand-vices and benches, a large number of screw-cutting lathes, two universal millers, several shaping machines and turret lathes, and a large planer. The class-room on this floor is fitted with a screw-cutting lathe and a hand bench. The smithy is on the lowest of the working floors; it contains about twenty down-draught forges, steam and power hammers and pipe cutting and threading machines, and the adjoining class-room is fitted with a down-draught forge, anvil, etc. Each shop in the building has a floor space of about 3,000 sq. ft. exclusive of the class-room, and the tool room, locker room, washing room, etc. An electric lift carries materials from the basement to the charging-platform of the cupola in the foundry.

The above instances of workshop equipment for engineering students could be extended almost indefinitely. The examples selected, however, will give an idea of the scale upon which the equipment is projected in most first-class colleges, whether university or technical, though, naturally, changes in the details are almost innumerable.

If the workshop equipment is lavish, the laboratory equipment, with very few exceptions, is still more so; and it is difficult within the limits of a paper not dealing exclusively with equipment to convey an adequate idea of its complexity or extent to those who have not visited the actual laboratories. Taking first the *Mechanical Testing Laboratories*, it was quite the exception to find such a laboratory with only a single large testing machine for tension, compression, and bending. In the Massachusetts Institute of Technology, for instance, the mechanical laboratories contain a 300,000-lbs. Emery testing machine, two Olsen testing machines of 100,000 lbs. and 48,000 lbs. respectively, a large torsion machine capable of testing a 3-inch shaft, a smaller torsion machine, numerous cement and other testing machines, apparatus for experiments on explosive gases, and a full 25-car brake plant. At Sibley College, in addition to a 300,000-lbs. Emery machine, there are three other large machines of 250,000 lbs., 150,000 lbs., and 100,000 lbs. respectively, besides numerous smaller ones; also torsion machines, oil testers, etc. At Purdue University, Indiana, there is again a 300,000-lbs. machine, with six smaller ones ranging from 30,000 to 100,000 lbs.; the largest machine can deal with vertical specimens 18 feet long. Among the miscellaneous pieces of apparatus may be mentioned an impact machine. There is also a full car-brake equipment for a train of 50 cars, with duplicates of each important part cut into sections to show details; and, further, there is a full-sized plant for testing brake shoes on an engineering scale. Other laboratories, varying chiefly in the details, but not much in the scale of equipment, could be referred to.

In the *Power Laboratories* the expenditure on buildings and equipment is often much heavier than in the mechanical testing laboratories just dealt with. Simple and compound engines of various powers, gas engines and oil engines, each arranged for experimenting under varied conditions, are to be found in all of them, whilst some have, in addition, triple-expansion engines and steam locomotives. For

instance, at the Columbia University, on Morningside Heights in New York, there are installed in a room, 200 feet long by 35 feet wide, a full-sized locomotive mounted on friction wheels with water brakes attached, a 120 H.P. triple-expansion engine with condensers and other accessories complete, several smaller engines, usually driving air compressors, the air from which is used to drive other engines, a complete hydraulic plant set up by Worthington & Co., a Westinghouse compressor and brake fully fitted, a calibration table for gauges, indicators, etc., and numerous smaller pieces of apparatus. Again, in the new Carnegie engineering laboratories at the Stevens Institute of Technology the power-room is in the basement occupying nearly the whole area of the site of the building. This room is full of steam, gas, oil, and hydraulic engines, the largest steam engine being of the cross-compound type; they are all fitted with brakes and measuring apparatus, and advantage is taken of the large amount of necessary piping to arrange experiments on steam flow, radiation, condensation, etc. There are also condensers of different patterns, arranged for careful experimental work. As in the preceding cases, numerous other examples could be given, but the above will probably suffice for an idea of the way in which this particular section of the equipment is usually planned and carried out.

For experiments on *steam raising*, advantage is usually, though not invariably, taken of the boiler plant required for heating and power purposes for the extensive buildings comprising the University or Institution, and which, therefore, does not come strictly under the head of educational equipment. It has, however, the advantage of necessarily being on an engineering and working scale, and where used by the engineering students is advantageous in many ways. At Columbia University the boiler room, which is available for students' work though under the administrative staff, contains eighteen Babcock & Wilcox boilers, aggregating to a total of 2,000 H.P. (nominal), and, as the University buildings are likely to be extended shortly, room is provided for duplicating this plant. At the University of Pennsylvania the power-house is worked by the engineering department and is not under the administration. It can therefore be used very fully for students' work, and is fitted accordingly. Where the general power-station is not thus used, separate boiler plant, installed to supply steam to the power laboratory, is usually employed for this class of experiments. At the McGill University, for instance, the boiler installation of the engineering building contains five distinct types of boilers available for experimental work. These comprise a Cornish boiler, a locomotive boiler, an internally-fired tubular boiler, two Babcock & Wilcox water-tube boilers, and a Yarrow water-tube boiler erected with a closed stokehold for working under forced draught.

The *hydraulic plant* is frequently installed in the general power laboratory or an annexe to it, but in some instances it is very extensive, and may be regarded as quite a separate and distinct section of the equipment. At McGill University, for instance, there is a hydraulic laboratory splendidly fitted. It contains an experimental tank 30 feet high and 25 square feet in section for experiments on the flow of

water through orifices free or submerged, a flume 35 feet long, 5 feet wide, and 3 feet 6 inches deep, with various weirs, a number of turbines of different patterns, and Pelton and other water motors, a hydraulic impact machine, a hydraulic ram, an accurate jet measurer, centrifugal and other pumps specially designed for experimental work, and the usual water meters, gauge testing apparatus, etc., etc.

Still more elaborate and extensive arrangements for hydraulic experiments have been provided at Cornell University, where the natural lie of the land lends itself to such arrangements and has been admirably utilised for the purpose. A masonry dam 200 feet long, built across a natural waterway, impounds water from a catchment area of 120 square miles. On the side of the lake so formed is built a canal 450 feet long, 16 feet wide, and 10 feet deep, provided with ordinary weirs, etc. Just below the dam a rapid fall in a natural gorge has enabled a laboratory building of three floors, 80 feet long and 80 feet high, to be erected; and there is also a University reservoir 145 feet above the level of the canal connected with the laboratory by a 10-inch pipe. The maximum available steady head thus provided is 225 feet. An electrically-driven truck running on rails fastened to the top of the walls of the canal gives facilities for haulage experiments. Elaborate arrangements have been provided for allowing different experiments to be carried on simultaneously without mutual interference. It need scarcely be added that there is a liberal supply of measuring apparatus of all kinds.

At the University of Michigan a new hydraulic laboratory provided with a large experimental tank was in process of erection. The tank is to be 300 feet long, 22 feet wide, and 10 feet deep, with a sluice-way at the bottom 24 inches wide and 20 inches deep.

When we turn to the *Electrical Engineering Laboratory* equipment, we naturally find much more diversity in the details, partly because of the rapidity with which this branch of work has been developed, and also perhaps because, being so recent, the actual lines adopted depend much more upon the individuality of the professors in charge than in the more settled work referred to above. Differences are also due to the greater flexibility of the chief experiments and the variety of apparatus available for them. In all the laboratories visited there was a very good, sometimes a very lavish, supply of testing instruments of the most recent patterns in actual commercial use, and usually, also, good and well-known standard instruments for calibration work.

In quite a number of cases the laboratory requirements had outrun the accommodation, though, doubtless not very long since this accommodation had been as lavishly provided for the electrical as for the other work. Where the accommodation was apparently ample it had generally been recently extended, as in the case of the Massachusetts Institute, at which an entirely new building for this purpose was erected in 1902, making available one large room 300 feet by 40 feet, together with numerous smaller experimental rooms and two lecture rooms. As this was the most recently provided laboratory visited, it probably represents the current ideas in the States as to the best

method of designing an electrical engineering laboratory for educational work. The fact that it has been and is directed by Dr. Louis Duncan, formerly of the Johns Hopkins University, is a guarantee of the scientific soundness of the work.

At the time of the writer's visit the equipment of this laboratory was far from nearing completion, some important machines not having been delivered and many of the machines already delivered not having been erected. Only a very general description is therefore possible. A boiler room, with two Babcock & Wilcox boilers, each of 250 H.P., adjoins one end of the long dynamo laboratory. At the end next the boiler room the main laboratory was being equipped with a complete electric lighting and power plant, consisting of a 480-kilowatt double-current generator and a four-phase alternator of about 140 kilowatts. These machines are to be driven by different types of engines provided with condensers and all accessories for experimental work. Of the lavish provision of machines and apparatus in the remaining and larger portion of the room only a summary is possible. There are, in addition to the above, two 125 H.P. and two 100 H.P. steam engines, about 27 generators and motors from 10 to 100 kilowatts, with an aggregate capacity of about 850 kilowatts, and some 15 large static transformers of a total capacity of about 400 kilowatts. In addition, there are a 50-kilowatt rotary converter and numerous small dynamos, motors, and transformers of a great variety of patterns. To handle the heavy machinery, a 10-ton electrically-driven overhead crane traverses the entire length of the laboratory. When all the machines are in position there will be placed in various parts of the room switchboards and testing-boards provided with the necessary testing instruments together with the resistances and all other accessories required in experimental work.

A not less important part of the equipment is the adjoining standardising laboratory fully provided with the most modern standard and testing instruments, with different kinds of current from the dynamo room, and with batteries and transformers for furnishing all varieties of current, potentials, etc., which are likely to be required for testing purposes.

The building also contains a number of small rooms for research, including four dark rooms for photometry and photography, and, in addition, an engineer's shop fitted with power-driven lathes, grinders, drills, and a 24-inch planer. Lastly may be mentioned a commodious lecture room, so fitted that lectures can be illustrated with experiments on an engineering scale, the necessary machines, if heavy, being brought into the room from the dynamo or preparation rooms on suitable trolleys running on rails sunk in the floor.

The electrical engineering laboratory at McGill University, under Professor R. B. Owen, although on a scale much less ambitious than the above as regards size, is very thoroughly equipped for good educational work. The dynamo room, placed in the basement of the engineering building, happens to be divided by a row of arches into two approximately equal spaces, one of which has been utilised for continuous current and the other for alternate current machinery.

The machines, whether generators or motors, stand in each room in two parallel rows, upon low wooden platforms about fifteen inches high, and having their tops slotted for clamping purposes. As a rule the machines in one row act as motors for driving the machines in the other row by horizontal belts. There are nine sources of current supply brought to a plug switchboard, from which leads are taken in chases sunk in the floor to the different positions on the dynamo platforms. Students are required to make their own connections at this board. The switches and testing instruments are on small tables, which can be wheeled to the side of the experimental machines, and other apparatus (*e.g.*, boosters, transformers, load resistances, etc.) are on low trolleys, which can also be quickly ranged alongside and connections made. There are altogether about twenty-five continuous current and twelve alternate current machines of different capacities and of types sufficiently varied to cover the whole range of modern electrical engineering work. In addition to the dynamo laboratory, there is a standardising laboratory fitted with the most recent standard instruments, and provided with continuous current at various voltages and alternate currents of different voltages, frequencies, and wave forms. There is also a separate room for high-voltage work (up to 50,000 volts), and photometer and special investigation rooms. The power-house, in a separate building, contains two full units, each of 70 kilowatts and two half units, whilst there is a large capacity chloride battery in a specially constructed room adjoining. This power-house is equipped as a modern central station with switchboard instruments, etc., and utilises the steam-raising plant already referred to.

It would be tedious to describe all the electrical engineering laboratories visited, for, as previously remarked, no two are alike except in the provision, lavish as compared with English practice, of machines and apparatus. A few special points, however, may be noted.

With scarcely an exception the supply of commercial testing instruments, often of expensive types, is very lavish, and if there is sometimes a deficiency in the instrumental equipment it is with regard to the more delicate and less frequently used laboratory instruments. In most places, however, the provision for research work ensures a more than adequate supply of these costly instruments and apparatus.

For electric traction work the University of Illinois at Urbana has, in conjunction with the Illinois Central Railway Company, built and equipped an experimental car which can be attached to any train so as to furnish data obtained under actual working conditions. The car was provided by the railway company, and equipped with its instruments and fittings by the university. Much valuable work, solving some important problems, has been done already with this car. Whilst referring to electric traction, it may be noted that the available laboratory equipment in more instances than the above is extended by facilities placed at the disposal of the schools by commercial companies. Thus the Brooklyn Polytechnic is allowed from time to time

by the local street railway company to use part of its track for experimental work, the company supplying the necessary current and an operating staff.

Amongst so much excellent equipment it was somewhat surprising to note, considering the not very recent important developments at Niagara and elsewhere, the general absence of specially equipped and separate electro-chemical laboratories. As an exception may be mentioned the electro-chemical laboratories at the University of Pennsylvania in Philadelphia and the University of Wisconsin at Madison. Some other places have made a start, however, and it is fairly certain that well-equipped laboratories for electro-chemistry, electro-metallurgy and cognate subjects will soon be the rule rather than the exception.

In another branch of electrical work, and one of especial interest to this institution, the equipment did not appear commensurate with the importance of the subject when compared with the equipment referred to above. This is with regard to the applications of electricity in signalling, especially in telegraphy and telephony. For the first of these subjects, beyond a few laboratory experiments for testing capacity, insulation, etc., little seemed to be provided. In telephony things were somewhat better, chiefly owing to the enterprise of companies manufacturing telephone apparatus. For instance, at Purdue University, at Ann Arbor, Michigan, and at the Armour Institute in Chicago a small automatic telephone exchange had been presented in each case by the manufacturing company, and at the first named a regular course in telephone engineering has been drafted, and is being given.

These brief references to equipment would be incomplete without a few words regarding the ample provision made for research. Not only does the general equipment include, as a rule, a great number of expensive and delicate instruments which would seldom be used by the ordinary student, and whose chief purpose is their availability for special investigations, but quite frequently heavy expense is incurred for equipment which can only be used for a particular research. Thus, at the Worcester (Mass.) Polytechnic a large oil transformer, approximately 6 feet by 5 feet by 4 feet, has been constructed and housed in a special building on the campus, to give facilities for high voltage research. With this transformer pressures up to 450,000 volts have been obtained, and experiments made on an overhead line specially erected for the purpose in the campus. To take another example out of many which could be cited: At Cornell University a special battery of thirty small dynamos, each giving 500 volts, has been installed, so that continuous current experiments up to 15,000 volts can be made. At the Johns Hopkins University in Baltimore, and the Clark University, Worcester (Mass.), the whole of the buildings and equipment have been provided for research work, and, needless to say, no expense has been spared. These brief references will give some idea, though doubtless an inadequate one, of the care with which this important side of higher engineering training is kept in view.

Staff.—It is fully recognised by many engaged therein that, what-

ever the other conditions may be, the success of any educational work depends very largely indeed upon the teachers, both senior and junior, entrusted with the instruction. It has been well said that the three chief requirements of a school or college are—firstly, men; secondly, men; and lastly and always, men. How, then, has this side of the question been handled in the United States and Canada, and with what results? The point was carefully investigated by the writer, particularly in his interviews with presidents of colleges and deans of faculties, and also with such manufacturers and employers as had given educational problems some consideration. On all hands it was agreed that for engineering the question was not quite so simple as for other subjects of education, and that, in the endeavour to staff the schools with the best men, the economic laws of supply and demand raised considerations more difficult to deal with in this particular form of education than in other forms. Sound academical training was, of course, recognised as absolutely essential, but, differently from most other branches of university and higher education, sound academical training alone, even when accompanied by a further or simultaneous training in educational method, was asserted to be not sufficient to make good engineering teachers. What are wanted are men who, in addition to these academical qualifications and the necessary enthusiasm for the work, have also had experience, and successful experience, as engineers. Even here there is a danger of misinterpretation, for it is not men who have been in practical life and have failed in it that are wanted, but men who have had practical engineering experience and have been successful in it. Such men, however, very readily command in the engineering industries salaries quite beyond what are found sufficient to attract good teachers in other subjects. It therefore follows that in order to obtain the best teachers in engineering much higher salaries must be offered than are offered for classical, mathematical, modern language, literary, or even pure science teachers. It is true that the educational work has attractions for some men which partly, but far from completely, restore the balance. Amongst these may be named the independence of a college professor, and still more the command of a well-equipped laboratory, especially such equipment as has been referred to above. Moreover, it is realised in the States and Canada that, however successful a man may once have been in any branch of engineering, yet, so rapid is the development, that unless he continues to engage to some extent in outside consulting professional work he cannot retain his efficiency as a teacher. It is, therefore, the universal custom there not only to allow such work to be done, but actually to require it, and to trust to the dean of the faculty and the president of the university or institution to safeguard the interests of the latter if any danger should arise from the teacher allowing his outside work to interfere with the proper performance of his duties.

The various considerations thus briefly summarised are much more clearly recognised in America than in this country, and consequently it was found that the salaries offered there for heads of departments and

responsible teachers are higher than the corresponding salaries in this country, even when allowance is made for an assumed difference in the cost of living. Most of the presidents, however, admitted that the salaries did not attract, except in special cases, the right kind of men for the heads of departments, and that to obtain such they will have to be substantially raised ; also that, notwithstanding the resources which will be referred to a little later on, the present financial position of the schools is not strong enough to offer the salaries for heads of departments which the necessities of the case require. For the understaff, even in responsible posts, oftentimes a man with mere academical qualifications has to be utilised, and the disadvantage of this result is keenly felt by those who are alive to the fact that to members of the understaff falls a great part of the routine work of education, which requires for its most successful development many of the qualities which are required for heads of departments.

Outside the colleges the opinions of thoughtful men engaged in the engineering industries pointed in the same direction. It was admitted that in some cases the colleges had the best men that could be procured for the work at the head of certain departments, but it was also asserted pretty strongly in some quarters that this was far from being the case all round. In fact, one college graduate who, since his graduation, has been engaged for ten years in successful engineering work, roundly asserted that he did not care if the whole of the equipment were scrapped if only by so doing money could be rendered available to secure the right kind of men as instructors. Others gave expression to the same ideas, though they did not couch them in such strong language.

Partly to overcome the difficulty, and also because in itself the plan is a desirable one, short courses of lectures are arranged at the best engineering colleges, to be given by representative and well-known engineers directly connected in actual practice with the subject of the course. This plan is not unknown in this country, though not followed to anything like the same extent. It partly meets the difficulty, but such peripatetic lecturers do not come into that intimate contact with the students which forms the chief ground of a successful teacher's work. Though very useful in their way, therefore, they are but palliatives wherever the main conditions have not been fully satisfied.

Before leaving the question of staff, a word should be said upon the ample power conferred upon the professors and teachers when appointed. Not only do they settle the curricula, and teach the subjects included therein, but the whole question of the awarding of the honours and of the graduating diplomas is placed in their hands without restriction. The principle acted on is that when a man is appointed a professor, or a responsible teacher, he must be trusted, and that any laxity in the work of his office, either in the neglect of the teaching, or in the undue lowering of the standard of the degrees conferred, must be counteracted by other means than interference with the details of the duties entrusted to him. The real corrective for such laxity, or for any neglect of college work in favour of private practice, comes eventually from the outside, although the dean of the faculty or

the president of the institution is expected to apply the corrective in any ordinary case. But if the graduates from any particular college are found on trial in actual life to be ill-prepared and ill-grounded for their work, the reputation of the college very rapidly falls—first amongst the employers and quickly afterwards amongst intending students. The success of a college is thus made to depend upon the quality of the products as tested in actual life and not as tested by outside examinations and examiners.

Finance.—As stated above, one of the reasons which led to the tour being undertaken was that it had been noticed that large sums of money had been spent in the United States and Canada within recent years upon higher education, in which engineering education is included. Reference has been made to the State contributions accruing under the Morrill Act of 1862, and the more recent Act of 1890, both passed by the Federal government of the United States, and applying to all the States. They have been supplemented by Acts of the State Legislatures applicable in each case to the State concerned only.

The money, as already remarked, has been applied for the purposes of higher education generally, and not particularly for engineering education. Separate figures for the latter are not available, but a return covering the eleven years from 1890 to 1901 inclusive, showed that some twenty-three millions sterling of private money had been spent during that period for the purposes named. More recent figures, given by Sir Norman Lockyer in his address in September last to the British Association at Southport, were to the effect that during recent years about forty millions sterling had been spent in the United States for this purpose. In addition large sums of money have been spent at the McGill University in Montreal, and at other places in the Dominion of Canada for the same purpose.

There is a general impression in this country that these large sums of money are due almost, if not entirely, to the beneficence of a few millionaires, such as the Macdonalds, the Rockefellers, the Leland-Stanfords and a few others. It is true that a large part of the sums named comes from such sources, but it is not realised how very large are the contributions towards the cost of higher education in the States, gathered in comparatively small amounts from a great number of individuals. Take one instance only, selected at random from the history of the University of Pennsylvania in Philadelphia. The Treasurer's report for this University, dated 31st August, 1902, shows that in the financial year to which the report refers, and excluding one large donation of £100,000, a sum not far short of another £100,000 was received by the University from private donors. These donors numbered about 400 separate individuals, and although there are one or two large amounts, including one of £10,000 and another of £5,000, the bulk of the money came from the large number of much smaller contributions. Such a widespread interest in education steadily maintained year after year in a single city cannot be paralleled here, though we must not forget the splendid response of Glasgow to recent appeals. It is no wonder, with the educated classes

taking such an interest in the work, that education goes forward by leaps and bounds. Well may the Provost say in his report that it "is a strong and encouraging evidence of the large-minded and increasing interest accorded to the University by citizens of the State of Pennsylvania and by our Alumni now living at a distance from their Alma Mater."

Unfortunately for this particular object of the inquiry much of the engineering education in the United States is given in universities, which include, within their purview, as would naturally be expected, all kinds of higher education. In some cases, therefore, it is impossible to separate out, either from the public official figures of the Bureau of Education or from the actual accounts of the individual universities, the exact financial aspects of engineering education considered apart from the other branches of education. The only method that suggests itself to the writer, a method which can be regarded as but roughly approximate, is to ascertain the percentage proportion of engineering students attending. Any figures obtained by applying this percentage to the gross amounts for the whole of the university will certainly err on the side of being smaller than the actual, for, on the whole, engineering education is more expensive both to equip and to maintain than the average of the whole of the subjects handled by a university.

Taking first the figures published by the United States Bureau of Education, the latest data obtained refer to the academic year 1900–1. They include returns for 473 universities and colleges for men and for both sexes, of which but the small proportion of 137 admit only men to the undergraduate departments. In addition, separate returns are given for 42 schools of technology, which, however, deal with agriculture, domestic science and often general science in addition to engineering work, so that even the returns from these cannot be taken as applying to engineering education only. In order that the subsequent figures may be interpreted in the approximate manner suggested, there is given in Table I., with the necessary percentages worked out, the actual number of engineering students in both the above classes of public institutions and in the different departments of engineering, including architecture, which is, especially in the United States, a quasi-engineering subject.

Dealing now with the above institutions for the epoch named, an abstract of their combined capital accounts is given in Table II.

The amounts appearing in the table fully justify the preceding remarks regarding the large expenditure in the past upon these institutions, and it must be remembered that the greater part of the expansion has taken place during quite recent years. No indication, however, is given in the returns of how much of this capital expenditure has been derived from public money and how much from private benefactions, but some indication of the magnitude of the latter for a single year may be gathered from the next table.

In regard to Income for the year 1900–1, particulars are given in Table III., in which the income of the same institutions derived from various sources is separately summarized.

The percentage amount of the ordinary income received from

TABLE I.—STUDENTS.

Subject.	Students in Universities and Colleges.	Students in Schools of Technology.	Totals.
Mechanical Engineering	2,990	2,633	5,623
Civil Engineering	2,645	887	3,532
Electrical Engineering	1,741	955	2,696
Chemical Engineering	398	138	536
Mining Engineering	921	588	1,509
Textile Engineering	—	234	234
Architecture	329	62	391
Totals	9,024	5,497	14,521
All Students	86,537	11,554	98,091
Percentage of Engineering Students	10·4	47·5	14·8

TABLE II.—CAPITAL EXPENDED AND INVESTED.

Subject.	Universities and Colleges.	Schools of Technology.	Totals.
	£	£	£
Grounds and Buildings ...	30,100,000	3,420,000	33,520,000
Apparatus and Machinery	3,600,000	804,000	4,404,000
Productive Funds ...	32,370,000	2,880,000	35,250,000
Libraries	2,430,000	150,000	2,580,000
	68,500,000	7,254,000	75,754,000
Proportion for Engineering (Based on Table I.)	7,150,000	3,440,000	10,590,000

TABLE III.—INCOME FOR 1900–01.

	Actual Income 1900-01.			Percentage of Ordinary Income (excluding benefactions).		
	Universities and Colleges.	Schools of Technology.	Totals.	Universities and Colleges	Schools of Technology	Both Classes
	£	£	£			
Tuition Fees	1,810,900	114,000	1,924,900	38·5	14·6	31·6
Endowments	1,328,000	126,500	1,454,500	28·3	16·2	23·9
State or Municipal Aid	837,500	174,400	1,011,900	17·8	22·4	16·7
Federal Aid	204,200	929,400	1,133,600	4·4	39·8	18·6
Other sources	518,000	54,400	572,400	11·0	7·0	9·2
Totals, Ordinary Income	4,698,600	1,398,700	6,097,300	100·0	100·0	100·0
Benefactions	3,509,000	16,900	3,525,900			
Totals ...	8,207,600	1,415,600	9,623,200			
Proportion of Ordinary Income for Engineering (based on Table I	486,000	665,000	1,151,000			
Proportion of Whole Income for Engineering (based on Table I).	854,00	673,000	1,527,000			

State, or Municipal and Federal sources (all of which is public money) is 22·2 per cent. for the universities, but reaches the high figures of 62·2 per cent. for the schools of technology. This is partly due to the fact that a large proportion of these are "Land Grant" colleges, drawing the special Federal subsidy already referred to. The actual amount in this case is much smaller than for the Universities, but then the number of students in attendance is much smaller. If, however, the total income per student be calculated it will be found to stand at £121 for the schools of technology and only at a little over £50 for the Universities. This supports the remark made above that the percentage method yields results which in all cases are below the actual for engineering students.

The total amount contributed in the year referred to in the table by the Federal Government for education of university rank, reaches the large total of £1,133,600, whilst the individual States and the municipalities together contributed £1,011,900 for similar purposes. Contrast

TABLE

...PITAL.	
...nt, ...g ...ty ...e.	Invested Funds.
	£
...00	710,600
...00	1,515,600
...0)	...
...00	2,672,000
	...
	1,261,400
	(89,400)
	2,823,000
...00	745,000
...00	51,400
	...
...00	114,800
	...
...00	106,400
	...
...00	68,000
...00	148,000
...00	11,600
	500,000
	...
...00	140,000

figures with the Government contribution to our Universities and ges, which, according to Sir Norman Lockyer, amounts, at present, 150,000 a year.

range to say, in the returns of the United States Bureau of ation, no figures are given for the normal expenditure which therefore be assumed to be the normal income given in Table III. varying amounts drawn from the benefactions of the year.

y the courtesy of the authorities of a number of the Colleges and tutions visited, I can give a more complete analysis of the financial ion in certain cases than is afforded by the returns of the Bureau ducation, and Table IV. presents, in abstract, particulars of their s and their income and expenditure, as far as I have been able to tain them. The returns supplied refer, as a rule, to the financial 1901–2, but in several instances the whole of the details for that were not deducible from the reports or the figures furnished by uthorities, and in such cases the blanks have been filled up as far ssible from the returns of the Bureau of Education for the year -1. The figures derived from the latter source are distinguished the others by being printed in italics. As in subsequent tables, the ges are divided into well-defined groups, the first group of six : (1) The universities of the East and the Massachusetts Institute chnology, so important in engineering education; (2) Four unities of the Middle West, which all have important engineering ols; and (3) Five technological institutions, regarding which the s available are much more scanty than in the previous cases. An pt has been made to ascertain the separate figures for engineering se institutions in which engineering forms a portion only of the tion offered, namely, the universities, but this attempt cannot garded as successful, though the few figures given may be of st.

aling first with the capital values, the large sums credited to ds and buildings and invested as capital assets in the older institu are especially noticeable. The leading place is taken by the nbia University, whose grounds and buildings are estimated at a l value of £1,650,000, and whose invested funds are £2,672,000. of this large amount has been accumulated during the last few Harvard University, Pennsylvania University, and Cornell rsity follow with substantial sums, the invested funds of the amed being £2,823,000. The Massachusetts Institute of Tech-, which is almost entirely an engineering school, values its ngs at £143,400, and has invested £710,600. In addition, in all nstitutions the expenditure upon equipment, which, in the table, es the machinery and furniture, is substantial. The more recently ed colleges in the West have not such heavy capital assets, but ns named in the table are also substantial, and much in excess of ng that we can produce for similar institutions in this country. eresting column in the capital account is the amount expended libraries of various institutions.

egard to income, the small amounts contributed by the State and palities to the older institutions are very conspicuous and in

striking contrast with their contributions to the more recent ones. In the case of the oldest universities the amount appears to be *nil*, and Cornell University and the Massachusetts Institute of Technology have small sums only, derived from the sources previously mentioned. On the other hand, the younger Western universities derive most of their income from public funds. In the column, headed "Benefactions," are set down the amounts contributed from private sources for the various institutions during the year 1901–2. From a comparison with figures for the preceding year, which are not included in the table, there is reason to suppose that the year selected is not in any way exceptional in this respect as regards the total, though the distribution of the amounts between the various institutions changes from year to year. The table exemplifies very strikingly the curious influence which the possession of State or other public support has upon private benefactions. The older institutions, which have practically no State aid towards their income, receive large contributions from this source, whereas the Western universities, with their large drafts upon the State, are left severely alone by private benefactors. In this country, unfortunately, the institutions which are not supported by the State or the municipalities do not receive the same substantial help from private benefactors as is accorded to institutions similarly situated in the United States, the amount of income from such sources in all cases within the knowledge of the writer being miserably small.

The figures given in the columns for expenditure are worthy of special study and speak for themselves. They justify the remark made above that private benefactions are drawn upon when the ordinary income proves insufficient.

The table will repay further examination than can be given here, but in leaving this section of the subject the writer desires again to call attention to the magnitudes of the figures involved, as well as to the distribution of the details under the various heads selected for the table.

II.—The Students Available and the Conditions of Entrance.

Not less important than the schools and the resources which they bring to the solution of the problem of engineering education, is the supply of material for them to work on in the shape of adequately prepared students. In order that an English audience may understand the position from this standpoint a brief description of the school system of the United States will be necessary. Such a description, however, can only be given in very general terms, the variety in the details of educational work in the different States being very great. The predominant outstanding fact is that for a very much longer period than in this country education has been carefully dealt with as a State question in all the States of the Union and in Canada, and this care of education extends from the lowest elementary forms up to the post-graduate work of the Universities and higher Colleges.

The basis of the system is the common or public school which the child is supposed to enter at the age of six, and in which he remains until he is ten years old. At ten years he is transferred, as a rule, for the next four years of his life to the grammar school, which forms a kind of intermediate stage between the primary and the secondary school, but in many such grammar schools, owing to the prevalence of utilitarian ideas, such subjects as algebra and geometry are left out of the curriculum, and as far as mathematics is concerned attention is paid only to arithmetic, and that more especially in its commercial aspects. Elementary English subjects are also taught. In some of the more advanced schools, however, literature, drawing and science now find a place. The pupils having remained in the grammar school until they are fourteen years of age, such of them as can afford to pursue their education to a higher level are supposed to be fit to enter either the High School with its classical and modern side, or the Manual Training High School, or Manual Training School, in which workshop instruction forms a large part of the curriculum. At this stage the usual courses extend over another four years, but in some of the Manual Training Schools they cover only three years; generally, therefore, by the time the student has gone through the whole course he is eighteen years of age. These schools take charge of the stage of education which is immediately preparatory to the entrance to the Universities and Technical Colleges, but the majority of the pupils do not carry their education further, but pass direct from them into ordinary life.

Taking first the Manual Training High Schools and the Manual Training Schools, a large proportion of the time, often approximating to one-third of the whole, is spent in the workshops, the remaining time being given to Mathematics, Drawing, Science, Literature, and Modern Languages. In the High Schools, on the other hand, there is a classical course, and often, in addition, what we should call in this country a modern side, in which Modern Languages and Science take the place of Latin and Greek. Mathematics is of course taught in all sections of the school. A feature of the work, which is somewhat curious to an English observer, is that the courses comprise a large number of what are called electives, that is, subjects amongst which the student can choose for himself, provided the programme which he finally decides upon fulfils certain easily followed requirements. Thus a student who is going in for law or medicine would naturally take classical languages, whilst the student who eventually intended to be an engineer would select science subjects, or might go to the Manual Training High School in preference to the High School proper. Whether it is desirable that a boy at the age of fourteen, especially after the somewhat restricted curriculum obtainable in many of the elementary schools, should have such liberty of choice placed before him is certainly a very debatable question, for it is a matter of common experience that at that age it is extremely difficult even for those who have been carefully observing the boy for some time to decide in which way his special aptitudes lie. In actual practice of course he is advised by his parents and by his schoolmasters, and thus probably the evils

of too great freedom in this respect are counteracted. One disadvantage of the method of electives is that it tends to the placing of the different subjects in somewhat water-tight compartments. The writer had recently a case before him in which a boy who had attended one of the High Schools in the States was fairly good at elementary algebra up to quadratic equations, but had absolutely no knowledge of geometry, his explanation being that the subject of geometry was in a different course which he would have reached in about twelve months' time had he remained in the school.

It might be supposed that the students of the manual training schools would be better prepared for technical engineering courses than those of the high schools, even on their modern side, but the teachers in the engineering colleges are by no means agreed that such is the case, and many of them consider that the students who come from the high schools, and even from the classical sides of the high schools, very frequently make better engineers in the long run than those who have gone through the manual training schools. The criticism which these teachers make is that the work in the latter is too much specialised and is too narrow, whereas the training in the high schools, being on a broader basis, produces students whose minds are better prepared for independent and original work than those who have been through the more circumscribed training. However this may be, the general result is that the students do not reach the entrance year of the technical engineering courses until they are eighteen years of age, and in the ordinary case until they have had at that age, and preparing them for their life-work, twelve years' training from the elementary school onwards.

The general position is thus in great contrast with that which obtains in this country amongst those from whom the students at our technical engineering colleges are drawn. The great majority of English boys of this type, with some exceptions which are far too few, attend, from the age of ten to fourteen or fifteen, a secondary school in which there is often no guarantee for the efficiency of the instruction. Some of these schools certainly do excellent work, but others turn out their pupils at the age of fourteen or fifteen with minds absolutely untrained in any direction and with a minimum of knowledge quite unfit for entrance upon any serious occupation in life. For engineering purposes, where a sound knowledge of elementary mathematics and a mind trained to think is absolutely essential, the result is disastrous. The inadequate training of the mind in alertness and in its use of the powers of observation in most of the public and other schools in this country has an important bearing on the question of the supply of well-trained candidates for the engineering schools, but it is too controversial a subject to be discussed here. But both because of the later age of entrance, and also because their general education, as a rule, has been carried to a higher point, it follows that the candidate for entrance into the technical courses in America is better equipped than those in this country to take advantage of the training of the professional school.

Again, not only is the intellectual quality of the supply inferior

in this country to that which is available in America, but, owing to the different social conditions, the quantity is not proportionately of the same bulk. For the best output of our public and private secondary schools the engineering profession has to compete with the demands and administrative requirements of the British Empire for the Home, Colonial, and Indian services, a demand which annually drains off quite an appreciable portion of the students who would otherwise look to the learned and scientific professions for their future life-work. Another great demand is made for the recruiting of the staffs both executive and scientific of the Navy and Army. To many men the attractions offered by the Civil Services and by Naval and Military careers are for many reasons much greater than those which engineering can put forward. For well-known reasons these attractions do not exist to anything like the same extent in the United States of America, and thus of adolescent manhood a much larger proportion than in this country turns to the learned and engineering professions.

Another class, from which the engineering colleges of America draw quite an appreciable proportion of their strength in earnest and capable students, is furnished by those who, not having been able to afford the luxury of a college training in early life, have acquired by dint of hard work and perseverance, or by some stroke of good fortune or inheritance, sufficient capital or resources to enable them to face a four years' college course, and thus to complete a training which was prematurely interrupted earlier in life. It is not too much to say that these men with their practical experience of life and its struggles form a very important backbone to the whole student class of the colleges. From the necessities of their previous practical training it follows that they are men endowed with grit and perseverance, who, having come to college with a well-defined purpose, do not intend to allow any obstacles to interfere with their aim, and thus they form a valuable nucleus round which the more earnest work of the institution gathers.

Conditions of Entrance.—The fact, however, that an intending student is eighteen years of age, and presumably has been at school since he was six years old, does not insure that he is fit to enter the professional engineering school, even though part of his training may have been of a quasi-technical nature. The schools, therefore, protect themselves with a more or less severe entrance examination from which there are, in many cases, exceptions in favour of those who have passed certain well-recognised public examinations.

The conditions of entrance to the various schools visited are so different that it is impossible to give an adequate idea of them in a mere summary; the following table (Table V.), therefore, has been prepared to exhibit in a concise form the conditions of entrance to the most important of the schools visited. These latter fall naturally into three groups. (1) Five Universities in the Eastern States, the McGill University, Montreal, and the Massachusetts Institute of Technology; (2) four Universities of the Middle West; and (3) five technical institutions.

Attention may be called to a few general points in this table. First, the minimum age of entrance varies from sixteen to eighteen, but although, therefore, the entrance age in some of the institutions is nominally below eighteen, I was informed verbally that, as a matter of fact, very few students present themselves until they have completed their eighteenth year, and that most of the institutions discourage entrance at an earlier age, although their published announcements allow of it. Secondly, in every case a more or less severe preparation in English is required; the examination besides testing the candidates in grammar and composition requires a knowledge of "set" literature, by which it is meant that certain English classics are selected beforehand for study, and the examination is based upon them and upon general English literature. Many of the schools also require the candidates to pass in some branch of History, ancient or modern. Thirdly, the requirements with regard to languages vary considerably. In only one school is Latin compulsory, namely, the Sheffield Scientific School of Yale University; in several other schools Latin may be offered as an optional subject. In regard to modern languages either French or German, and frequently both, is compulsory at all the schools except Purdue University, Indiana, and the Stevens Institute of Technology, New Jersey. Turning to Mathematics, algebra, as far as quadratic equations, and frequently as far as the binomial theorem, is required, whilst plane, solid, and spherical geometry are compulsory in most cases. Trigonometry is not so frequently made obligatory, but there are several schools which require it. Greater diversity exists with regard to physics, chemistry, and other sciences. In most of the schools a knowledge of none of these is absolutely required, and they are placed in the elective category, but in some schools an elementary knowledge of one science subject and evidence of laboratory work in it is obligatory. Drawing scarcely figures at all as an entrance subject and a knowledge of the use of tools is not often allowed to count.

As a counterbalance to the stiffness of the subjects scheduled, it will be noticed that the entrance examinations being held usually twice in the year, and sometimes oftener, there are in most cases special conditions by which weak candidates can pass the various subjects in sections, either in two successive years, or partly at the June and partly at the September examination. This provision obviously lessens the difficulty of passing the examination, and as further the candidate who has not passed in all subjects can frequently be admitted on condition that he makes good the deficiency during the first year of his College work, the entrance of still weaker candidates is facilitated.

Even with all these qualifications, however, an inspection of the table will show that the entrance requirements in nearly every case are stiffer than, for example, the matriculation examination at the University of London. In the latter, neither English nor elementary mathematics are carried to as high a stage, one language only, which may not be Latin, is required, and two other subjects selected from a long list. Taken altogether, the examination cited is not so difficult as the examinations for entrance to the engineering schools of America and

Canada, as detailed in Table VI., except in the fact that it has to be passed all at once.

In conclusion, it may be noted that in more than one of the schools, and especially those of well-established reputation, there is a tendency to raise still further the conditions of entrance. Owing to causes referred to elsewhere in this paper, the number of students annually seeking admission to college engineering courses is severely taxing the resources and accommodation of most of the schools. The latter can afford, therefore, to pick and choose whom they will take, and it is obviously of advantage to the subsequent work to be able to ensure that it starts from a sufficiently high entrance level.

Fees and Living Expenses.—It will perhaps be most convenient to deal with this matter in the present section, though it does not strictly belong to the conditions of entrance. It may be said, however, that the amount of fees to be paid and the living expenses to be faced have in many cases a great influence upon the choice of the school to which the student seeks admission. For convenience of reference the writer has embodied in the annexed table particulars regarding fees and living expenses in the principal institutions which he visited. In addition, as intimately connected with the subject, he has added in the last column an approximate estimate of the number of scholarships available in each institution as far as the data at his disposal permits.

Dealing first with fees, it will be observed that they range as regards tuition from nothing up to £52 a year. The fees are highest in the Eastern universities, which, as has already been noted, do not derive so large a proportion of their income from the State as the newer "land grant" colleges in the Middle West. In the latter the tuition is practically free to residents of the State in which the college or university is placed, but some small fees are charged for materials, library, and other expenses. In the technical institutes the tuition fees range from £16 to £41, and are therefore very similar to the fees charged in this country.

The burden, to the students, of the fees is relieved in many cases by the liberal supply of scholarships. Thus at Cornell University and at Yale there are 566 and 445 scholarships respectively. These, however, apply to all the faculties of the University, and the writer has not found it possible, with the data at his disposal, to separate out those which are available for engineering students only, and he has not considered it worth while to worry the various authorities for the separate statistics. The outstanding fact is that there is a very liberal supply of scholarships for the poor students who can show that they are deserving of this assistance. In many cases, *e.g.*, at the Massachusetts Institute of Technology, the number of scholarships is not definite, but funds exist from which scholarships are given, graded according to the necessities of the different cases and to the extent to which the funds permit.

In regard to living expenses, figures have been obtained in most cases from official sources and estimates. A column is given in which are specified the estimates of the lowest cost at which it is possible to live near the institution concerned, but a second column gives what is

TABLE VI.—ANNUAL FEES AND LIVING EXPENSES DURING SESSION.

College or Institution.	Tuition Fees.	Other Fees.	Living Expenses. Lowest.	Living Expenses. Moderate.	Number of Scholarships.
	£	£	£	£	
Massachusetts Institute of Technology	52	—	52	62	40 State plus others.
Cornell University ...	26	4	64	95	566
Columbia University	30	£2/10	47	92	87
Yale University ...	30	—	—	103	445
Harvard University ...	30	—	42	62	253
Pennsylvania Univer.	30–41	2–4	72	103	140
McGill University, Montreal	32	1	20	35	12 (Applied Science).
Michigan University, Ann Arbor ...	6	2	27	39	—
Illinois Univ., Urbana	0	5	27	43	265
Wisconsin University, Madison	Free to Residents £6 to Non-Residents	4–6	41	72	9
Purdue University, Indiana	Free to Residents	6–7	30	50	—
Stevens Institute of Technology, N.J. ...	£30, Res. £46, Non.	8–10	49	65	24
Brooklyn Polytechnic	41	4	—	—	7
Armour Inst., Chicago	16	0	40	60	2
School of Practical Science, Toronto ...	£14 1st year £16/10 2nd £18/10 3rd	—	16	—	—
Worcester Polytechnic	30	2	27	36	65

considered to be the cost of living in comfort without extravaganc[e]. As a rule the institutions are non-resident, but in some cases hostels a[re] provided, and in many universities there exist students' clubs, kno[wn] as the Greek Letter Clubs, members of which manage to live mo[re] cheaply than the other students of the university. Another fact[or] which has a great influence upon the cost of living is the position [of] the institution, there being a great difference between those which a[re] placed in the centres of large towns and cities and those which a[re]

practically in the open country. The rule, however, is not a strict one, for it is curious to note that Cornell University, which is practically in the country, is returned as being more expensive for living at than the Columbia University in the City of New York. A point to note in passing is the comparatively low cost of living at the Canadian institutions.

III.—The Work of the Schools.

When we turn from the conditions of entrance to the intellectual fare which is provided for those who are successful in obtaining admission within the portals of the various institutions, we find that the diversity and complexity of the details to be reviewed is considerably increased. So much is this the case that it is almost impossible to draw any general conclusions to which there shall not be numerous exceptions, the courses agreeing only, as a general rule, in the amount of time that is to be devoted to passing through them, viz., four years, but even on this point there is not complete agreement.

Whether this period of time is sufficiently long to obtain the objects aimed at without undue waste of the valuable time of the student is one upon which the leading authorities in the United States express an adverse opinion. The general tendency of the conclusions arrived at is that the time requires either to be lengthened in the professional school, or that still further preliminary training, such as is given by an undergraduate course for a science degree, should be required from the candidates. This opinion is acted upon in one or two cases. For example, at the Sheffield Scientific School of Yale University the course, which will be described later, covers only three years, and qualifies for a Bachelor's degree, but for full professional training a further two years' course is required leading up to the Master's degree, part of this course being spent in post-graduate work outside the walls of the university.

Neglecting the one or two instances in which the courses are only three years long, broadly speaking it may be said that the first two years out of the four are devoted to education which, except for the introduction in most cases of workshop work and mechanical drawing, does not differ very much from what might be expected to be carried on in a good secondary school with a strong scientific bias.

The devotion of so much time to subjects, especially English and modern languages, which are non-professional and should be well taught in a secondary school, would seem to imply that, although the average age of entrance is so late as eighteen years, the preparation up to that stage has not been as thorough as it should have been. There is doubtless some amount of truth in this criticism, and the fact that so many of the students come up with so little real training may be partly due to the very great variety of educational methods and aims which abounds in the States. It has been remarked elsewhere that many of the teachers of professional subjects view with more favour the students who have passed through the high schools than those who have passed through the manual training schools, the

reason given being that the minds of the former students are better trained to think and more receptive than those of the others. It is a matter for serious consideration whether the excessive amount of time given to manual work in the manual training schools has not been dearly purchased at the expense of starving the time which should have been given to mental training. It is a mere commonplace to say that such mental training can be as well given through the medium of mathematics, mechanics, chemistry, and physics, as it can through the medium of the classical and modern languages. The presence of these high school students, however, would necessitate courses in mechanics, physics, and chemistry, but should not require English and modern languages, which are perhaps necessary for the students from the manual training schools.

Looking over the conditions of entrance, one would have been disposed to suppose that secondary educational subjects could have been dropped for professional ones almost immediately, and in one or two instances they are so dropped. For example, the Columbia University engineering course and the courses at the Toronto School of Practical Science do not include English, history or modern languages; whilst at Sibley College a very small amount of time is given to modern languages, and nothing to English or history. A similar remark, except that a slight amount of time is given to English and none to modern languages, may be made with respect to the McGill University engineering course.

Whatever the explanation may be, the rule is that in the first two years a fair amount of time is given to mathematics, English, modern languages and elementary experimental science, and it is chiefly in the workshop and drawing office that the specialisation towards engineering is apparent during these two years. In fact, such are the exigencies of the time-table that laboratory work in physics is in more than one instance postponed to the third year, although lectures in that subject are included earlier in the course. Early in the third year specialisation begins to show itself much more prominently, and in the mechanical and electrical engineering courses, to which the writer paid most attention, mechanical technology and electrotechnics are more or less dealt with. In many cases, however, the severely engineering educational work does not bulk too much in the third year, but in the fourth year a crowd of engineering subjects is frequently introduced, and in a comparatively short time the student is expected to cover a great amount of ground.

To describe adequately the details of the education in a form in which the actual course of the work could be followed readily, it would be necessary to set forth the subjects and the hours given to them for each separate year in a fair number of representative institutions. Considerations of time and space will not allow this to be done, and to render the analysis still more manageable the statistics which follow will be confined to the courses of mechanical engineering and electrical engineering in which the writer's interest chiefly lies.

In Tables VII. and VIII. there is set forth for these two branches of engineering the total number of hours occupied in various subjects and

Subjects.	Massachusetts Institute of Technology.		Sibley College, Cornell University.		Columbia University, New York.	
	Hours.	Per Cent.	Hours.	Per Cent.	Hours.	Per Ce
1. English History	135	4·4	...		...	
2. Modern Language	270	8·9	102	2·6	...	
3. Mathematics, Pure and Applied ...	277	9·1	170	4·2	256	6·5
4. Mechanics, Physics and Chemistry: Lectures and Exercises ...	226	7·5	408	10·1	672	17·0
5. Mechanics, Physics and Chemistry: Laboratory	179	5·9	536	13·2	352	8·9
6. Mechanical Technology: Lectures	440	14·5	326	8·0	566	14·3
7. " " Laboratory	210	6·9	180	4·4	200	5·2
8. Freehand Drawing and Descrip. Geometry	180	5·9	238	5·9	...	
9. Machine Drawing and Design, including Graphics	510	16·8	884	21·8	1120	28·3
10. Structural Design	...		...		...	
11. Electro-technics: Lect. and Design	30	1·0	153	3·8	224	5·6
12. " Laboratory ...	...		...		48	1·2
13. Metallurgy	15	0·5	...		32	0·9
14. Law and Economics	60	2·0	...		...	
15. Miscellaneous	20	0·7	...		32	0·9
16. Shop Work	462	15·3	918	22·7	452	11·4
17. Thesis Work	...		136	3·3	...	
18. Heating and Ventilating	15	0·5	...		...	
19. Surveying	6	0·2	...		...	
Total Time: Hours	3035 + Thesis	100·1	4051	100·3	3954 + Thesis	100·2
Total Time: Weeks	120		136		128	
Total Time: Years	4		4		4	

Yale University.		Brooklyn Polytechnic.		Armour Institute, Chicago.		School of Practical Science, Toronto.		Worcester Polytechnic.	
Hours.	Per Cent.	ours.	Per Cent.	Hours.	Per Cent.	Hours.	Per Cent.	Hours.	Per Cent.
102	5·1	273	7·2	170	4·2		...	94	2·0
408	20·4	96	2·5	102	2·5		...	201	4·2
217	10·8	286	7·6	340	8·3	208	7·1	263	5·5
411	20·6	365	9·6	194	4·8	468	16·0	510	10·7
68	3·4	235	6·2	514	12·6	490	16·7	262	5·5
239	12·0	501	13·2	590	14·5	248	8·5	298	6·3
		186	4·9	204	5·0		...	224	4·7
135	6·7	147	3·9	170	4·2	64	2·2	234	4·9
380	19·4	455	11·9	468	11·5	1059	36·2	505	10·6
	...	109	2·9		...	50	1·7		...
	...	51	1·4	68	1·7	66	2·2	62	1·3
	...	17	0·4	204	5·0	156	5·3	124	2·6
	...	30	0·8		..	26	0·9		...
	...	49	1·3	92	2·3		...	93	2·0
39	2·0	51	1·4	68	1·7		...		...
	...	576	15·2	640	15·7		...	1620	33·9
	...	330	8·7	204	5·0		...	256	5·4
	...	30	0·8		...		...		...
	...		...	40	1·0	89	3·4	30	0·6
1999	100·0	787	99·9	4068	100·0	2924	100·2	4776	100·2
102		128		136		78		124	
3		4		4		3		4 + Summer Course.	

groups of subjects at different institutions during the whole period of training. The institutions have been grouped in the same order as in Table V. which gives the particulars of the entrance conditions, and below each number specifying the hours occupied in a subject is printed in italics the percentage which these hours represent of the whole minimum time which the student is required to give in passing through the whole course. The table does not include the amount of time which is to be spent in preparation and in home work, for, except in a very few instances, it was found impossible to get particulars of this time, and therefore it has been omitted altogether. Its omission will partly explain the large differences shown by the tables between the total hours required by different institutions. Thus the low figure of 3,143 hours given for mechanical engineering at the Massachusetts Institute of Technology is supplemented by 2,857 hours of home work required from each student.

In most of the institutions the courses for mechanical and electrical engineering are identical for the first two years, and in some for the first three, the bifurcation between the students studying the different branches occurring either at the commencement, middle, or end of the third year. But, although there is some separation, there is usually a moderate amount of overlapping, and the two classes of students still continue to take some subjects in common. It will be noticed that in several cases time is devoted to such apparently outside subjects as law, economics or business engineering. The amount, as a percentage of the total, is not very high, but the institutions concerned attach great value to this training, which is usually given towards quite the end of the course, and is intended to fit the students to face the practical problems of life more thoroughly equipped than if their college training had been confined entirely to a strictly engineering course.

The subjects in the table included under the heads of mechanical technology and electrotechnics deal very thoroughly with the various sub-divisions of these subjects, but considerations of space render it impossible to give more minutely particulars of such divisions. Under "mechanical technology" is usually included the consideration of strength and elasticity of materials, prime movers of all kinds, hydraulics and hydraulic machinery, machines and machine tools, and, less frequently, marine, railway, and mill engineering, whilst under "electrotechnics" there are treated, as a rule, all kinds of continuous and alternate current machinery, apparatus and measuring instruments, the generation and distribution of electric energy, electric traction, lighting, and so forth. Sometimes, but not often, courses in technical telegraphy and telephony are included.

Reference has already been made to the equipment of the laboratories, and, in these, experiments in the various branches of the subjects are conducted upon a full engineering scale. The nature of these experiments will be gathered better from a perusal of the references already made to the equipment rather than by consulting the tables just given.

Turning now to specific subjects, attention has already been

called to the purely literary work included in the earlier years. Mathematics is usually carried through the various stages of the infinitesimal calculus which are so useful and necessary to engineers. The amount of time given varies between somewhat wide limits, many of the schools only taking the subject during the first two years. Physics and chemistry are taught in the earlier years, but owing to the exigencies of time-tables the laboratory work does not always run synchronously with the lecture and exercise work in these subjects. There are, for English ideas, too many instances of the laboratory work being postponed until the lecture work has been almost, if not quite, completed. In fact, it may be said generally, though there are some exceptions, that the laboratory work in these subjects is not given so prominent a place as it is in the best English technical schools; chemistry claims the greater share, and physics is sometimes left very much in the cold, notwithstanding the splendid equipment at the disposal of the various institutions. The figures regarding laboratory work given in the table will be particularly interesting to English students.

The teaching of mathematics and physics to engineers is a subject into which the writer inquired somewhat closely, and particularly as to whether the teaching of these subjects should be placed in the hands of the pure mathematician, and of the pure physicist, or in the hands of men who, whilst being necessarily well trained in the subject matter, are primarily engineers. The question does not arise so much in the polytechnics and technical institutes as in the universities where these subjects are also taught to large bodies of students who are not taking the engineering courses. Most of the authorities consulted were strongly of opinion that this teaching, where engineering students are concerned, should be placed in the hands of men who have been thoroughly trained as engineers, and that it should be differentiated very markedly from the teaching of the same subjects to the other classes of university students. It was pointed out that there need be no sacrifice of real mathematical or real physical training, and even little change of syllabus in arranging such courses, that the teaching by an engineer to engineers could be made as thorough a ground-work for sound mental training as if the more academical practice were followed and that the gain to the students would be very great indeed. It is quite true that in some of the universities exigencies of staff or finance do not allow the suggested plan to be followed, but in the majority, even of these cases, the engineering classes are so large that special courses of lectures, exercises, and laboratory work in mathematics and physics are given to them apart from the Arts or Science students, and then the special nature of the audience is borne in mind by the instructors, even though the latter may be nominally attached to the other faculties of the university. The difficulty of following what was usually considered the better course was often accentuated by the fact that owing to financial reasons, the junior staff in these subjects had frequently only an academical training, the salaries offered being too low to attract trained engineers.

Mechanical drawing and design in most cases occupies a deservedly commanding position, though the actual number of hours and of the

percentage time allotted varies through very wide limits. The drawing offices, or draughting rooms as they are called, are usually very capacious, well lighted, and almost ideal in their equipment and arrangement. The work appears to be thoroughly well done, and its importance fully recognised.

In regard to practical work in the metal and wood workshops, great diversity of practice exists, and inspection of the tables shows that it varies from almost nothing at Yale to a very preponderating number of hours at the Worcester Polytechnic. Many of the schools adopt the practice of requiring each class, as it is called, that is the men who are to graduate in the same year, to carry through some more or less elaborate piece of constructive work, such as a screw-cutting lathe, a large planer, or even a triple expansion steam engine. The whole design of the machine dealt with is supposed to be evolved by the class, the drawings made and the work carried through the shops from beginning to end, with perhaps the exception of some of the heavy castings, which are obtained from outside. On the other hand there are one or two institutions, and one especially in the front rank, viz., the Massachusetts Institute of Technology, in which the ideas underlying the shop work more nearly accord with the best English practice, the keynote of which the writer believes was sounded for the first time twenty years ago in the workshops of the Finsbury Technical College, viz., that the students' time in the shop is to be devoted not so much to the acquirement of mere manual dexterity as to the purpose of familiarising each student with the various types of machine and other tools, their functions and limitations, the best cutting speeds for different materials, and similar matters. The Massachusetts Institute has gone so far as to change recently the title of its workshops to "laboratories," thus emphasising the fundamental idea of the collegiate position of such shops, and clearly differentiating them and their purposes from commercial workshops. One cannot but think that if the attempt to copy the commercial workshops is carried too far other branches of work in the schools must suffer, and it must not be forgotten that these latter and important branches of the work are such as can be far better given in a school than under any possible conditions in actual commercial work.

One or two minor points may be noted in conclusion. In many cases visits to works are organised upon a large scale, and although this method of supplementing the teaching of the technical school is not unknown in this country, it seems to be more thoroughly systematised on the other side.

Another important point is the way in which the attention of the senior students is directed towards the current literature of the various subjects. In more than one institution each member of the senior class has a particular technical journal assigned to him, and he is required to enter up upon index cards particulars of all the important papers in a form in which they can be filed for ready reference. The cards, after being inspected by the instructors, are typed in duplicate, the indexing student keeping one copy and the other going into the general index of the department.

Summer courses are arranged at some of the institutions, but these are usually attended by students who are not taking the regular winter courses. The best of the latter employ their time during the summer either in visiting workshops or in taking actual work with some manufacturing firm.

An important part of the work of the fourth year is the preparation of a graduation thesis. The original intention of including such work in the time-table was undoubtedly to stimulate each student to produce, before he left the institution, a piece of original work which should be of some value in the development of science or of industry. In actual practice, however, the amount of original work produced is not very great, and it can be said fairly that only the best students do work which may be correctly dignified by the name of research. The average student, even when close to the end of the course, has not yet sufficiently assimilated his teaching, and is still hampered with the intellectual exertion required to digest the great amount of material which is being presented to him. By research here is, of course, meant true research and not merely the following out of some particular investigation on perhaps new materials by well-known methods, the details of the investigation containing nothing which is new except, perhaps, the particular material which is being experimented upon; much work grandiloquently called research is of this latter nature, but would be more correctly described as exploration. The theses when approved are sometimes printed, but in most cases, whether printed or left in MS., are bound and placed among the records of the work of the institution. The writer had an opportunity of inspecting some of these, and it is as a result of that inspection that he makes the above remarks. Much good sound practical work is undoubtedly done, and whether it may be called original or not, it is a distinct advantage to the student that he should be obliged to carry through an important piece of work of commercial or scientific value from beginning to end. Owing to the difficulties of finding sufficient apparatus, or a sufficient number of subjects, the students often work in groups of two or more, and the thesis produced is the joint work of the group. This to some extent detracts from its value, as it is impossible to say who is responsible for the final form or the more important details. Notwithstanding these drawbacks, however, the writer considers that the system is one which might well be followed in the best schools in this country, in some of which, although the senior students have opportunities for assisting in research, such work is not made a necessary condition for graduation or put so fully into the hands of the student.

Post-graduate Work.—The tables given include only the work for graduation, but in most of the colleges post-graduate courses of a very elaborate nature are organised, and it is in these courses that the best work of the college is done, the carrying out of which, in the opinion of the writer, chiefly justifies the lavish expenditure upon apparatus and equipment. As most of my hearers will recall, some important researches have issued from these laboratories in recent years. The post-graduate student is allowed to select his particular line of work, and in most cases the full resources of the laboratory and the help of

the professorial and artisan staff are placed at his disposal to carry the work through. It would be interesting, did space permit, to describe, with some detail, some of the work which was observed in progress in the different laboratories, but, apart from the fact that the best of this work will certainly be published in due course, the remarks just made, combined with the previous references to laboratory equipment, will give a good idea of the facilities offered and the consequent importance of the work attempted.

Whilst referring to post-graduate work mention may be made of those colleges or universities which in America have been established entirely for such work. Of these the writer visited two, namely, the well-known Johns Hopkins University in Baltimore and the Clark University in Worcester, Massachusetts. In both cases original work of the highest order was being carried out, and at the former the writer had the opportunity of seeing the celebrated Rowlands' ruling engines at work, ruling diffraction gratings.

The interesting point to note, however, is that neither of these Universities has been able to maintain entirely its post-graduate character. At the Johns Hopkins University, as the work developed it was found that the graduates coming from other Universities for post-graduate work were so varied in their mental equipment and previous training that a preliminary course was necessary in many cases to fit them for the higher work. So numerous were these cases that it was considered necessary to establish undergraduate courses of the ordinary type, to which not only the graduates coming from a distance were admitted, but also the inhabitants of Baltimore and Maryland. In the Clark University at Worcester, a much younger institution, full undergraduate courses have not yet been established. The writer was informed, however, that work, of lower grade than post-graduate work, is now being undertaken, and it seems probable that this work will extend in the future.

The point is of immediate interest in London in view of the proposals which were made last year for a large central technological institute, for amongst these proposals, one, the desirability of which has been discussed, is the establishment of an institute entirely for post-graduate work. In the writer's opinion educational development is not yet ripe enough in London for such an institute, and it is doubtful whether, in view of the experience of the Universities referred to above, such an institute can ever be run entirely for post-graduate work. In fact the relegating of such work to a separate institution would cause it to lose one of its chief educational advantages, for there is no doubt that the presence of the few post-graduate students engaged upon the highest work is one of the best practical incentives to the undergraduates who necessarily come into contact with them socially and otherwise if the institute is properly organised on all sides. Such intercourse produces an *esprit de corps* and a pride in what the school has done and can do, the value of which cannot be overestimated.

Students.—Such being the curricula provided, it is important to examine how far it is taken advantage of by students, together with two or three subsidiary points cognate to that part of the inquiry.

Figures have already been given (*see* Table I.) of the total enrolments in the universities, colleges, and technical schools, and also separately of the enrolments in engineering subjects taken throughout the United States; but these figures do not specify in what proportion the students are divided between the different stages of the work or how many of them are taking full courses, or, on the other hand, are attending as post-graduate students, or as special students. Under the latter name are usually included the students who take partial courses only, and some of whom may not be doing very high-grade work. Figures on this point are not easily obtainable for the whole of the country. The writer has therefore collated in the following four tables the figures which he has been able to obtain from some of the institutions visited. In these tables the numbers enrolled for the year 1902-3 are divided into six classes, namely, the four separate years of the ordinary course, the "post-graduate" students and the "special" students, where such exist. Table IX. relates to all branches of engineering, including architecture, whilst Tables X., XI., and XII. are for mechanical, electrical, and civil engineering respectively. In a few cases it has not been possible to make this division, and in still more it is not possible to divide between the mechanical and electrical students, for in certain institutions no distinction is made between these. In the later cases the numbers have been put entirely into Table X. and included under mechanical engineering. The totals in each year are given and in Table IX. the percentage of each class with respect to the general total of students dealt with is also worked out. It will be noticed that, although there is a considerable leakage between the first and second year and quite an appreciable leakage between the second and third, there remains a considerable number of students who are carrying the work through and are doing the highest work in the regular courses. In addition the post-graduate students form a very respectable minority. The leakage in the early years is accounted for in the usual way, namely, that students who find that they have no special aptitude for engineering drop out altogether, and that other students are requested to repeat a year's work before being passed on to the subsequent year. There are curious differences in the percentage leakage between the different institutions, but it would be carrying the analysis to too great a degree of minuteness for the purposes of this paper if these differences were enlarged upon. Any one who is sufficiently interested to go into the question will find in Table IX. all the data before him.

Viewing these numbers and the numbers previously given from a broad standpoint, one is justified in calling attention to the very great contrast which they exhibit towards anything that we can produce in this country in educational work of similar standing. That there should be in these 16 institutions as many as 1,134 students doing fourth year work, and 237 post-graduate students, is a fact, the significance of which it is difficult to realise fully. For purposes of comparison the following figures (see p. 401), published two years ago by the Association of Technical Institutions, give for Great Britain the number of day students, *15 years old and upwards*, taking complete technological engineering courses in university colleges and technical institutions.

Standing in College.	1 Massachusetts Institute of Technology.	2 Cornell University.	3 Columbia University.	4 Yale University.	5 Harvard University.	6 Pennsylvania University.	7 McGill University.	8 Michigan University.	9 Illinois University.	10 Madison University.	11 Purdue University.	12 Stevens Institute.	13 Brooklyn Polytechnic.	14 Armour Institute. 1903-4	15 Toronto School of Practical Science.	16 Worcester Polytechnic.	Totals.	Percentages.
First Year	433	475	189	241	69	106	77	229	251	224	294	118	28	219	142	81	3,176	34·9
Second Year	278	332	165	201	79	68	66	130	136	132	249	64	15	141	106	60	2,222	24·4
Third Year	230	189	138	125	46	65	50	80	113	86	149	59	18	71	66	41	1,526	16·8
Fourth Year	195	176	79	140	34	43	34	45	60	69	93	50	17	32	22	45	1,134	12·5
Post Graduate	170[3]	18	5		...	...	3	...	24	3	10	...	3	...	...	1	237	2·6
Specials	455	9	27	31	85	17	20	...	55	71	...	...	14	...	...	20	804	8·8
Totals	1,608[2]	1,199	603	738	313	299	250	484	639	585	795	291	95[1]	463	336	248	8,946[2]	100·0

NOTES.—[1] Includes Art and Science students. [2] Deducting 153 names counted twice. [3] The number of post-graduate students in engineering was not ascertained; the total number of post-graduate students was 170.

TABLE X.—STUDENTS OF MECHANICAL ENGINEERING, 1902–3.

	1 Massachusetts Institute of Technology.	2 Cornell University.	3 Columbia University.	4 Yale University. 1901-2	5 Harvard University.	6 Pennsylvania University.	7 McGill University.	8 Michigan University.	9 Illinois University.	10 Madison University.	11 Purdue University.	12 Stevens Institute.	13 Brooklyn Polytechnic.	14 Armour Institute.	15 Toronto School of Practical Science.	16 Worcester Polytechnic.	Totals.
First Year ...	[1]...	356	38	[1]...	13	54	See Table IX.	[1]...	71	[1]...	103	118	See Table IX.	59	80	[1]...	...
Second Year ...	56	252	28	29	17	33		46	41	24	110	64		39	43	14	796
Third Year ...	43	136	31	33	10	41		33	30	17	58	59		15	30	16	552
Fourth Year ...	34	137	18	...	13	14		20	18	15	39	50		9	...	19	386
Post Graduate ...	[2]...	18	[2]...	...	...	...		...	11	[2]...	7	...		...	...	...	...
Specials	88	5	[3]...	...	17	...		...	22	[3]...	...	...		...	...	...	...
Totals ...	[6]221	[4]904	[8]115	[5]62	70	[4]142		[5]99	193	[7]56	317	[4]291		122	[4]153	[5]49	

NOTES.—[1] Students not classified into different branches of engineering till end of first year (see Table IX.). [2] Subjects studied by post-graduate students not specified (see Table IX.). [3] Subjects studied by special students not specified (see Table IX.). [4] Includes electrical students. [5] Exclusive of first-year students. [6] Exclusive of first-year and post-graduate students. [7] Exclusive of first-year, post-graduate, and special students. [8] Exclusive of post-graduate and special students.

TABLE XI.—STUDENTS OF ELECTRICAL ENGINEERING, 1902–1903.

	1 Massachusetts Institute of Technology.	2 Cornell University.	3 Columbia University.	4 Yale University. 1901–2	5 Harvard University.	6 Pennsylvania University.	7 McGill University.	8 Michigan University.	9 Illinois University.	10 Madison University.	11 Purdue University.	12 Stevens Institute.	13 Brooklyn Polytechnic.	14 Armour Institute.	15 Toronto School of Practical Science.	16 Worcester Polytechnic	Totals.
First Year	[1]...	Included in Table X.	46	[1]...	16	Included in Table X.	See Table IX.	[1]...	71	[1]...	120	Included in Table X.	See Table IX.	84	Included in Table X.	[1]...	...
Second Year ...	43		37	13	16			18	21	45	81			53		26	353
Third Year... ...	37		29	17	9			12	26	39	41			33		10	253
Fourth Year ...	38		13	...	2			10	7	30	30			16		13	159
Post Graduate ...	[2]...		...	...	...			...	1	...	2			...		1	...
Specials	48		...	...	18			...	12	...	...			...		...	78
	[6]166		[8]125	30	61			[5]40	138	[7]114	274			186		[5]50	

For Notes see Table X.

TABLE XII.—STUDENTS IN CIVIL ENGINEERING, 1902–1903.

	1 Massachusetts Institute of Technology.	2 Cornell University.	3 Columbia University.	4 Yale University. 1901–2	5 Harvard University.	6 Pennsylvania University.	7 McGill University.	8 Michigan University.	9 Illinois University.	10 Madison University.	11 Purdue University.	12 Stevens Institute.	13 Brooklyn Polytechnic.	14 Armour Institute.	15 Toronto School of Practical Science.	16 Worcester Polytechnic.	Totals.
First Year	[1]...	97	28	[1]...	14	33	See Table IX.	[1]...	74	[1]...	71	See Table IX.	See Table IX.	38	...	[1]...	...
Second Year ...	56	74	31	20	18	25		49	56	55	58			19	...	13	474
Third Year ...	42	43	26	11	12	11		30	40	28	50			15	...	9	317
Fourth Year ...	31	31	15	...	8	13		14	22	21	24			4	...	6	189
Post Graduate ...	[2]...	...	[2]...	...	...	...		...	7	...	1			...	...	...	...
Specials	58	...	[3]...	...	20	...		...	7	...	...			...	...	...	...
Totals	[6]187	245	[8]100	31	72	82		[5]93	206	[7]104	204			76		28	

For Notes see Table X.

Courses.	First Year Students.	Second Year Students.	Third Year Students.	Students who have attended more than 3 years.	Totals.
Engineering	1,141	724	347	52	2,264
Mining ...	118	29	15	4	166
	1,259	753	362	56	2,430.

The contrast between the 56 students in Engineering and Mining who were attending courses beyond the third year in Great Britain and the 1,371 fourth-year and post-graduate students in the United States and Canada, is almost startling in its vividness, and is difficult to realise even if no account be taken of the other differences between the two classes of students referred to in various parts of this paper.

IV.—The Products and the Attitude of Employers.

The chief value of such training as is described in the best of the curricula contained in the foregoing section is not the actual detailed information which the student acquires so much as the grip of fundamental principles and an alertness of mind which enables the possessor, almost unconsciously, to apply those principles to any problems as and when they arise. In addition, he should acquire the attitude of a mind which is never content with the beaten track, although that track may be a good one, but is always on the look out for fresh and more advantageous developments, and is willing to face the risk of failure which new developments, however scientifically directed, may involve.

Such an attitude of mind, together with the fundamental knowledge which alone renders it of value, the writer believes is acquired by a fair number of the graduates of the most up-to-date institutions in the United States and Canada; and the employment of such trained talent in the industries in which science and its applications play an important part cannot but have a marked effect upon real progress.

It remains therefore to inquire whether this talent and intellect when trained is, as a matter of fact, drafted into the service of the engineering industry, and in examining this question the writer carried his inquiries to the two principal classes of people who were likely to know the facts, namely, to the principals and the deans of the engineering faculties of the universities and colleges visited, and to the employers of engineering labour on an extensive scale to whom the majority of the graduates must look for at least the commencement of their careers subsequent to leaving college. Without exception the officials interviewed asserted that, far from having any difficulty in placing the graduates turned out year by year from the engineering courses, for the last few years the graduate class has had every one of its individual members engaged for remunerative work before the completion of the

course at the college. Inquiries amongst managers and employers confirmed this claim advanced on behalf of the colleges, though in some instances a doubt was expressed as to whether in the case of the less known and more academic of the institutions the claim could be fully substantiated, but in these cases, however, it was conceded that the best graduates had no difficulty in obtaining positions, and it was only the tail-end of the class which might have to wait for some months or even abandon the attempt to get immediately remunerative employment.

Turning to the other section of the evidence sought, important testimony is borne by the following letter addressed in June, 1902, to the heads of the various technical training colleges and institutions by Mr. James A. Gayley, the first vice-president of the United States Steel Corporation.

UNITED STATES STEEL CORPORATION.

Office of the First Vice-President.

New York, 25th June, 1902.

MY DEAR SIR,—The United States Steel Corporation is well provided with reserves of raw material; has splendidly equipped works and an efficient organisation, but in the matter of organisation, we cannot, in the natural order of things, see as far into the future as we are able to with respect to raw material or equipment, and as the equipment of brains and energy are just as important to this corporation, we are desirous of working out some plan by which one or more of the most promising graduates each year, from the departments of Chemistry, Metallurgy, Engineering, etc., in certain Technical Schools, can be provided with employment in the constituent companies of this corporation, wherein they would have every opportunity to learn the practical and business side, and we would be securing the services of the best trained brains for the development of our manufacturing interests. As such men must compete for advancement with the young men, who are a product of the works and largely self-educated (and who, I might say, are to be found no mean competitors), we want such as are practical in their judgment and have a plentiful supply of common sense. We want men of brains and ambition, who are disposed to devote their energy in industrial lines; men with potential energy and originality. We do not want men whose primary claim to recognition lies in the attainment of high-term grades for recitation, as some men are quicker than others at absorbing information and reciting it, but not at digesting it. As many institutions have several technical departments, it is not our desire to take each year the best student in each course; but considering the courses in the aggregate, it is our desire to secure from such aggregation one or more of the men having qualifications as outlined above, to place them in departments for which they have been specially trained, and to give them special opportunities for one year at a stipulated salary. The future will take care of itself. We want ability; will recognise it and pay for it.

We would be pleased to have your views as to such a plan, and any suggestions relating thereto.

Yours very truly,
(signed) JAMES GAYLEY,
First Vice-President.

To the President of —— University.

The principle of action indicated in the above letter is to train men ready for opportunities and openings when they occur and not wait until the necessity arises before beginning to look for the man. This principle, in various ways, is acted upon by many firms in addition to the United States Steel Corporation, and is so obviously correct where large and developing businesses are concerned that it needs no argument to enforce it.

Many other firms are on the look out for the graduates who are in process of manufacture at the schools, and I was assured, by more than one, that it is found increasingly difficult to get what is wanted. For instance, the experience of the New York Telephone Co. is, that some years ago it was only necessary to ask for the lists at the end of the session in June, in order to procure all the men for whom there were vacancies. But for the preceding two years the month of May has been found too late to give notice in order to obtain a sufficient supply of suitable men, whilst in 1903 the inquiries went out before the end of March for the men who were to graduate in June.

These and similar facts naturally lead to an inquiry into the nature of the employment and the prospects offered to the men immediately on leaving college, and also into the attitude of employers towards them.

Taking the latter question first, the writer found that many of the large employers have made it a *sine quâ non* for entrance to any position which may lead eventually to a place on the scientific staff, that the candidate should have passed satisfactorily through the full four years' course at an approved technical institution, whether university or other, and such firms will not consider the application for admission of any candidate, however powerfully he may be recommended by personal friends, unless he can produce a college or university diploma. This fact alone is of great importance in its reflex action upon the colleges, for it brings home the commercial importance of a college career to many who, under the older conditions, would have been content that the engineering aspirant should commence his training in the works.

The extent to which the large engineering works absorb the yearly output of the colleges can only be realised by quoting an actual case. For instance, Professor Elihu Thomson, whose name is so well known on this side of the Atlantic, informed the writer that the General Electric Company take into the testing department at Schenectady about 250 and into the Lynn works from 40 to 50 college graduates every year, and that, at any rate in the latter works, 15 or 20 more would be taken if they were available. None but college-trained men are admitted as pupils, and at Lynn the period of pupilage is nominally

two years. *No premium is required,* but living wages are given at the start and are advanced as soon as a man shows that he is worth more. With capable men such advancement invariably comes long before the two years period expires, whereas unsuitable men, who lack qualities such as tact, power of handling men, etc., which no college or other training can supply, automatically drop out because their wages are not advanced. At Schenectady the men are taken on to the testing staff on probation and are given 15 cents per hour for the first six months and 17½ cents per hour for the second. As the working week is 56 hours, these figures work out to about 35s. and 41s. per week, which is certainly more than a mere living wage. At the end of the period the men who show engineering talent and originality are passed on to further work in the test room and the shop for promotion to the engineering staff. Next to these, the men who have good practical engineering knowledge but fall short of the highest excellence are drafted into the office, at good salaries, to manage the scientific correspondence. A still lower grade is entrusted with installation work up and down the country, whilst those who are not even good enough for this are utilised in various ways. The writer was assured that very few turn out utter failures and have to drop engineering altogether.

As another example, the method adopted by the Westinghouse Electric Manufacturing Co. may be cited. This Company, like the General Electric Co., will not take any but graduates into its works. In the first instance they are taken for 685 hours (3 months) on trial; if approved a binding contract is made for two years at a starting wage of £7 12s. per month, but I was assured that this contract is seldom worked out, as most of the men are advanced to responsible posts at a higher salary before the end of the period.

The Western Electric Co., of Chicago, adopt a somewhat different system in dealing with the college-trained men. For them they have three grades of apprenticeship, the first grade (A), consisting of the picked men, have three years' training in the shops and drawing offices leading up to the acquirement of full telephone engineering knowledge and experience. During these three years the salary is £2 per week for the first six months, £3 per week for the following year, £15 10s. per month for the next year, and £21 per month for the last six months of the period. At the end of the time the men who have stood the test satisfactorily are put on a salary of £250 per annum for another six months, and then graded according to ability. The next grade (B) of apprentices is for men less talented, and leads through the shops and drawing offices to the position of shop superintendents, whilst the third grade (C) leads up also through the shops and drawing offices to employment on the commercial side.

Turning for a moment from electrical firms, the American Sheet Steel Corporation take college-trained men of any faculty in preference to men who have not been to college, but more especially take men trained in technical engineering. The reason given for preferring college-trained men, even if not graduates of the engineering school, is that such men have been trained to think and to systematically attack any new problems presented to them. They are passed through the laboratory and

various shops and, if already trained as engineers, are supposed to obtain a clear grip of the whole run of the manufacturing business in about 1½ years. If of the right sort they then rise rapidly but the incompetents are dropped. The starting salary is £15 10s. per month, and the positions led up to are worth from £375 to £625 per annum.

In the Baldwin Locomotive Works a special class of apprentices, consisting entirely of graduates of colleges, technical schools or scientific institutions has been formed. These apprentices are only required to serve for two years instead of the three or four years required from others, and are given considerable choice as to the particular kind of shop work they will pass through. The commencing salary is higher than the salary given to the other apprentices in their final year, and, commencing at 30s. per week, it rises during the two years to 47s. per week. During this two years' work the graduates are said to quickly find their level, a fair number of them drifting into the commercial side of the work, and only the exceptional ones being retained on the engineering and manufacturing side.

The last example may be drawn from a non-manufacturing employment. The rule of the Superintendent of motive power in the large generating station of the Manhattan Railway Co., is to take for the higher staff of the station only college graduates. Although for the lower posts he finds the Manual Training School students useful, he will not promote any of them beyond a certain rank without further training, for he finds that, although they may do routine work perfectly, in an emergency or for any special work their lack of training becomes painfully evident. Correspondence pupils he finds even worse, as might be expected.

Reference has already been made to the principle which is acted upon by many manufacturers of preparing men in advance for emergencies and necessities which may arise. Rather striking examples of the application of this principle may be drawn from the procedure of the General Electric Company, and of the Westinghouse Company when contemplating the establishment of manufacturing works in England. In each case a number of men were taken from England over to America to be trained in the ways of the Company, so as to be ready to take positions in the new works when the latter commenced manufacturing. It seems to have been argued logically that well qualified Englishmen trained in American methods would, in certain positions at any rate, be able to deal more effectively with English workmen than Americans, however well trained for work in their own country, and in answer to inquiries which the writer made, he was assured that the Companies had every reason to be satisfied with the result.

It must not be supposed, however, that all the manufacturing firms in America refuse to receive as apprentices for their technical staff any but college graduates. Instances have been given of important firms in which this is the rule, but the writer found quite as many firms in which, although college graduates have a preference, others are not debarred from aspiring to important posts and there are still other firms in which either no preference is given to graduates or graduates are not received at all. It is interesting to note that the businesses carried on by these latter firms are such as are not in a very rapid state

of development, or in which the changes in the products necessarily occur very slowly, and in which, therefore, the standard patterns of the articles produced remain with very little alteration from year to year. They are in all cases firms unconnected with the supply of electrical apparatus and machinery, and range over tool making, printing machinery, testing machinery, and general mechanical machinery of various types.

It has previously been remarked that the willingness, and even eagerness of the employers to engage the graduates turned out of the engineering schools, has an important reflex action upon the supply of students to those schools. In addition to this help, however, the employers support the schools in other ways, amongst which may be mentioned liberal donations of apparatus and other assistance in the direction of equipment.

It would be tedious to give a list of all the apparatus which was pointed out to the writer as having been given by firms to the various laboratories visited. It may be mentioned that the American Car Builders' Association has fitted up in the laboratory of the Purdue University a full brake equipment for a train of fifty cars, and in addition, has included duplicates of the principal parts of the apparatus cut into sections, so as to show working details. The same Association has also put down in the laboratory a complete plant for testing various patterns of brake shoes under practical working conditions. Again, in the electrical laboratory of the Purdue University, there is an automatic telephone exchange, given by the manufacturing company. A similar exchange has been erected in the laboratory of the Armour Institute, Chicago. In several laboratories there is a full set of apparatus for experiments on the Westinghouse brake, this apparatus being either given outright by the manufacturing company or supplied on very favourable terms. Again, in the last annual report of the Director of Sibley College, Cornell University, published in November, it is announced that the Baldwin Locomotive Works, of Philadelphia, is constructing for the department of railway mechanical engineering a special locomotive for use as an experimental machine and in instruction, and the Director confidently appeals to the friends of the College for from £5,000 to £10,000 to house it and to provide the necessary accessory apparatus, as there is no suitable building available or proper apparatus in hand. As might be expected, the assistance sometimes takes the form of what is practically a permanent loan. Thus in the mechanical laboratory of Purdue University, a full-size car bed for an electric tramcar has been deposited on loan. These instances, out of many which were brought to the writer's notice, will be sufficient to show that the employers give material assistance in this direction towards the equipment of the laboratories.

In addition to helping with the equipment, the employers give facilities for the students to make tests, and to examine work under actual commercial conditions, in fact, shop visiting often figures as a distinct part of the annual time-table. Some of these facilities have already been referred to in dealing with equipment, but there can be no harm in mentioning such again here. For instance, the Pennsylvania

Railway Company, the Lackawanna Railroad, the Baltimore and Ohio Railroad, and other companies allow the students of Cornell University, and probably of other engineering colleges as well, to travel on the engines, and to take diagrams and make other tests under working conditions. The Street Railway Company, in Brooklyn, allows the students of the Brooklyn Polytechnic to experiment upon a little used part of its track, supplying for the purposes of the experiments the necessary current and operators and material equipment in the form of cars, the Polytechnic supplying the necessary measuring instruments. At the University of Illinois, the Illinois Central Railway Company and the University have jointly constructed an experimental car with which very important testing work has been done. The Railway Company built the car and the University supplied and fitted it with necessary measuring instruments. This car can be attached to any kind of train, and has been sent long distances with students on board making experiments on all kinds of roads and under very varied conditions of haulage and working. It has also been employed for some very important experiments in connection with a proposed electrification of the section of the New York Central Railway on Manhattan Island.

Another direction in which the employers help the colleges is in practically throwing open their workshops during the summer vacation for the undergraduates to obtain workshop practice under commercial conditions. No undergraduate who is willing to work need be at a loss in America to find a shop in which he will be welcomed and given every reasonable facility. The firms giving such facilities say that they are amply repaid by becoming acquainted in advance with the real value of the men who are graduating, and in the data they acquire for making their selections when the time comes. This fact is worthy of note in connection with recent proposals in this country for the adoption of the so-called "sandwich" system of training engineers.

References to the attitude of employers towards the colleges will not be complete without some mention of the criticisms which the writer heard in the course of his tour. Enough has been said to show that the schools are very favourably regarded by many manufacturers, but the latter are not, therefore, blind to what they consider to be faults, nor do many of them think that there is no room for improvement. The most general criticism was that in many cases the training is too superficial and too apt to overload the student with a large and confused assortment of facts instead of training him in principles, this being in a large measure due to attempts to deal in too much detail with a crowd of subjects, especially in the last year of the course. More than one critic, well qualified to speak, regarded the training in many of the schools as too theoretical, and as giving too much attention to literature, but on the other hand there were some who spoke of the literary training as extremely important because of the facility which it gives to the men in writing well reasoned and intelligent reports. Another criticism was that in many cases the equipment was too lavish; some reference has already been made to this in the preceding pages.

On the subject of the proper value and aims of college shop work

no real concensus of opinion could be obtained. Many critics held that the schools attempted too much, and especially in the direction of trying to reproduce too exactly the conditions of commercial workshops. On the other hand some held that the schools did not go far enough in this direction, but the balance of opinion was much the other way, and it was considered far better that the students should get their commercial training in commercial workshops rather than that the valuable time given for college training should be taken up to any large extent with merely manual work. It was argued that the college training should not go farther than making the student familiar with the details and principles underlying each machine and giving him a good knowledge of its uses and possibilities, such points as cutting speeds, etc., being thoroughly dealt with.

A criticism which will be interesting to members of this Institution was made by more than one well-known official connected with telegraph and telephone work. It was that the colleges are too much concerned in turning out what may be called "kilowatt" men, and do not pay sufficient attention to the "milliwatt" men, the consequence being that it is very difficult indeed for telephone and telegraph companies to obtain the trained assistants which they require for the development and carrying on of their business.

Another subject of which complaint was made as being neglected by the colleges is Electro-Chemistry, for which there is very little provision in most of them, but this deficiency is rapidly being made good and soon will cease to exist. In addition, two or three practical men criticised the teaching of mechanical drawing as not being what it ought to be in training men who are expected to use their knowledge in commercial drawing offices.

The objection so frequently met with in this country that the college-trained men are eaten up with conceit of their attainments and so set the practical men of the factory or workshop against them, was found chiefly surviving as a tradition of what used to be the case. The disappearance of this objection seems, however, to have been comparatively recent, and probably the commencement of its disappearance dates from the time when the most far-seeing of the schools, recognising the danger, proceeded to modify their curricula and simultaneously to inculcate upon the students the importance of the work which had to be done outside after the college training is complete. Whatever the reason may be, the "know-it-all" college man has almost vanished from the workshop, though, as has been remarked, a tradition of him and his eccentricities still lingers.

V.—The Influence on Trans-Atlantic Engineering.

This section of the subject has been given the prominence of a special heading, not so much because of the extent to which it can be developed, as to draw attention to its importance. It will be readily understood that it is very difficult, if not almost impossible, to trace, except by inference, the influence which the colleges, with their splendid endowments and equipment and their numerous graduates, are pro-

ducing upon the engineering industry of the country. That this influence must be great is shown inferentially by several methods of deduction :—

(1) That the employers liberally support the schools by taking their graduates, by giving facilities to the undergraduates for work in their vacations, and last, but not least, by liberally contributing towards equipment.

(2) That the graduates are taken on at a living wage, *no premium being required*, and that a fair chance is given to capable men to rise irrespective of family or other influence.

(3) To any one who has walked through any of the large electrical engineering works, the presence of the experimenter and his testing staff in every part of the works shows that the brains drawn from the colleges are being utilised.

(4) The rapid development of the engineering industries in the United States during the last ten years warrants at least the cautious deduction that this development is due to some extent to the utilisation of the brains trained in the schools, though, of course, the older men who have directed the movement had not, in many cases, the advantage of a college education.

(5) Incidentally the quickness with which any new idea, wherever originating throughout the scientific or engineering world, is taken up and worked for all that it is worth in America, may be held to be fair evidence of the influence of the college-trained graduate, well posted in the literature of his special branch of engineering, and keenly alive to all discoveries.

VI.—Applications to Great Britain.

In the preceding pages the lessons for home consumption lie mainly on the surface and do not require special emphasis. Still it may be advantageous, even at the risk of some little recapitulation, to review briefly the chief conclusions arrived at and their bearing upon problems now being worked out in Great Britain.

The education debates of the last two years, though deplorable from the point of view that very often education was the last thing debated, have at least served one good purpose in arousing the attention of the country to some of our most glaring educational defects, especially in the direction of secondary education. It has become quite fashionable to say that our secondary education is in a state of chaos, and there is a certain amount of truth in the stricture, especially as regards organisation and co-ordination, and with respect to the preliminary training necessary for the budding engineer it is hampered by the worship of the "humanities" to the practical exclusion of science and its splendid opportunities for intellectual training and development. It has also been pointed out over and over again that until this secondary education is put upon a different footing and we begin to receive the products of the new *régime* in the universities and colleges, we cannot hope to make much headway with such professional education as is being dealt with in this paper. The immediate practical

question is, Can we wait? To place secondary education upon a proper footing will take years, and certainly the present generation of schoolboys cannot reap the benefit. Must we then pause in our development of engineering education until the necessary adjustments have been made in the secondary schools and a new generation has had time to take advantage of them and to come forward fully equipped for the higher work? There can only be one answer to this question. Modern trade developments are moving so rapidly that, for the moment and until the reforms of secondary education now so strongly advocated have been accomplished, it would be disastrous to stand still, and we must press forward our technological education and make the best of the materials which are available. At any rate a proportion of the secondary education which is being given is good, and we shall obtain at least some students who are well fitted to take advantage of more than all that we can put before them.

To make the best of this material it is worth while to consider in what respects we are behindhand as compared with the United States and Canada in our handling of and provision for higher engineering education. Our deficiencies may be classed as follows:—

First.—In the lack by many of our leading manufacturers of support and encouragement of the work of the colleges, either by offering positions to the best college graduates to start their works training at a living wage, or by actively assisting the colleges in the same ways as their American competitors, as detailed in previous parts of this paper. The attitude of the British employer towards the college-trained men is greatly influenced by the premium system which so largely prevails in this country, for in many cases the first question asked from a young man who seeks to enter the works of an engineering firm, is not what his previous training has been, but what premium he or his friends are prepared to pay. Cases in which pupils offering a premium are refused, because of their lack of training, are probably few and far between. Worse still, in many cases the only advantage the pupil purchases with his premium is having the run of the shop or works without any real discipline, on the off chance that he will "pick up" the necessary knowledge and experience. What struck the writer most in his investigations in America was the entire absence of this system, and the prevalence in its place of the system of offering to the college-trained men commencing positions at a living wage, and the almost universal comment of the employers that it *paid* to do this. It is not too much to say that the existence of the premium system in this country acts as an incubus upon the supply of brains for the engineering industries. The vested interests involved, however, are so great, that it is only an overwhelming sense of the importance of the subject that induces the writer, with much trepidation, to give expression to his convictions, the result of careful examination and study. That he does not stand alone he is assured by noting that *Engineering*, in its editorial columns,

has recently given expression to similar views. He is aware that there are firms who do organise courses of instruction for their pupils, but at the best the greater part of the instruction in fundamental principles cannot be given under as good conditions as should obtain in well staffed and well equipped technical colleges, such as are indicated in this paper as being necessary for the work.

Secondly.—Even were the employers prepared to take students on the same relative scale as their American competitors, our present schools are neither equipped nor staffed to produce in sufficiently large numbers the trained men who would be demanded. But, as it is, the best products of our existing schools do not get that encouragement at home which should be forthcoming, and a fair proportion find in the States the opportunities which are denied to them at home. The writer found not a few instances of men trained at the Central Technical College, and elsewhere, holding their own well against the graduates of American colleges.

Thirdly—and in great part as a consequence of the first point noted, parents and guardians in this country have not yet been educated to understand how essential, in view of the great developments during recent years, college training is to the success in the future of a candidate for the engineering profession. Influenced by the well-known arguments about the advantages of so-called "practical" training, they pay the premium demanded in the fond hope that they have provided the youth with a secure path to professional success in life. The frequent disillusion at the end of the apprenticeship term is pitiable, and the writer has met with many cases in which it might be fairly described as heart-breaking.

To sum up, it will be noted that under each head it is the employers and manufacturers who hold the key of the position, and it is for them to say whether the leeway, shown in this paper to be so considerable, is to be made up within this generation, or postponed until it is too late. Vested interests are the greatest difficulty, but is it too much to hope that they will not continue to block the way?

It must not be supposed that the writer considers that well planned and well carried out college work is the "be-all" and "end-all" of engineering training. On the contrary, he recognises the absolute necessity for actual commercial training, either in the factory or in the works. But all his observations tend to the conclusion that to launch a youth straight from the secondary school into the midst of such work, even where there are arrangements for organised training, leads, at the best, to a grievous loss of valuable time at a period of life which would be much more profitably employed in the specialised work of the technical college. Sooner or later the outside work must come, and the training will not be complete without it. But he is strongly of opinion that, at the earliest, it should be not sooner than after two years of college training, and that even then it should be interlaced

with further college training. This is of course a form of the "sandwich" system so much debated last year. The modification favoured by the writer is that which introduces into a four years' college course two long summer workshop periods, one between the second and third, and the other between the third and fourth, years of college work. But even then, the workshop experience will require to be supplemented by say another year of practical commercial work. Such a course has been started this winter at the Northampton Institute. It has a very important incidental advantage over the "all works" course, in that those who by temperament or otherwise are unfitted for an engineering career, of whom a certain number will always be trying to enter the profession, can and will be weeded out during the two first years, and thus the "works" will not be troubled with them at all. Only the picked men will get as far as the end of the second year when outside workshop training commences.

Turning now to our immediate resources for advancing towards a better state of things, it would be a mistake to ignore what has been done in this country before and since the passing of the Customs and Excise Act in 1890, and the Technical Instruction Act in 1889. These Acts certainly have given an enormous impetus to technological education, in which engineering education of a kind has bulked very largely. The first-named Act has been in operation for thirteen years and the second for fourteen years. A recent return shows that in the year 1901–2, £1,057,399 were expended in England and Wales under the above and cognate Acts, and this expenditure, with varying amounts for the figures but of the same order of magnitude, has been going on for thirteen years. What have we to show for all this money, which is not small? The result resembles a confused mosaic, the different pieces of which are of very different value and give very different returns for the expenditure. Scholarships have been lavishly instituted, and in many cases have brought forward good students who otherwise would have remained in obscurity and without proper opportunities for their mental development. Evening technical schools have been very vigorously developed, almost solely because the way for these had been paved by the previous work of the Science and Art Department in teaching, and aiding the teaching of, the elements of science. But as regards strictly engineering education, very little out of these large sums of money has been applied to higher engineering education, which is the chief subject of this paper, and the importance of which it is impossible to exaggerate. In a few instances a good beginning has been made, and amongst these may be specially named the new municipal school at Manchester, upon which a capital sum of £350,000 has been spent, and which in its day departments has been organised with a special view to higher technological education. It is worth noting in passing that this school, as regards the personal element of the students, carries on and extends the work done during many previous years under the auspices of the City and Guilds of London Institute and the Science and Art Department. Up and down the country schools less ambitious have been founded, but for the higher work the equipment has been starved, and in most cases the salaries

offered have not been sufficiently high to attract the right kind of teachers, but so much has been said elsewhere on the subject of staffing in this paper, that it need not be referred to further here.

In addition we have had the expenditure during many years of the grants, both for buildings and for maintenance, disbursed by the Science and Art Department now merged in the Board of Education. These grants in their total for a period of years amount to a considerable sum, a fair proportion of which ought to have been deflected towards technological, and especially towards engineering work, had the ideals with which the Department was founded some fifty years ago been kept in view.

Nor must we forget that twenty years ago the Finsbury Technical College was founded by the City and Guilds of London Institute, and was followed very soon afterwards by the Central Institution (now the Central Technical College) at South Kensington. The expenditure on these two Colleges is not included in any part of the public money referred to above. At the time they were opened these colleges were far in advance of anything that then existed in the United States or Canada, and had they been followed up by similar institutions on an adequate scale throughout the country we should still be leading the way. Instead, our American cousins, quick to note a good thing, have taken up the ideas then started and have worked them up to the splendid position noted in this paper and far surpassing anything which has been done here.

The practical question is, whether anything can be done to improve the application of the existing resources and what new resources are required. In regard to the existing resources something might certainly be done to direct their application more towards higher engineering education. Within the last few years certain scholarships have been earmarked for commercial education, for the improvement of which strong reasons exist, but it might well be taken into consideration whether similar earmarking for engineering education should not be applied to the scholarships. In the opinion of the writer the country is as much in want of one as of the other. That the great productive industry of engineering has as large a claim for attention in this respect as the distributive industry of commerce might well be maintained. It is worth noting that, notwithstanding the source from which they are drawn, the number of students winning the scholarships above the elementary grade who take up engineering as their life work is surprisingly small, at any rate in London. Last June out of the 179 Intermediate London County Scholars in attendance, only twenty-five were taking engineering courses, although it may be said that the whole 179 were drawn from the class who might be expected to feed the productive industries rather than the distributive.

Again, we have certain endowments specially directed towards the improvement of engineering education. The most munificent of these is probably the endowment given some thirty years ago by Sir Joseph Whitworth from which the present Whitworth Scholarships and Exhibitions are maintained. It is worth inquiring whether the system now in vogue for awarding these scholarships and exhibitions is the

one best calculated to advance real engineering education. The subject is too large and complex to be discussed at the end of an already unduly long paper, but the writer notes it as one that is well worth serious consideration.

In regard to the Imperial funds at the disposal of local authorities it is difficult to ascertain how much is devoted to the furthering of the education of which this paper is the subject. Certainly not much when taken as a whole, but here again a minute ciriticism of the present application of such funds would lead us too far afield. What may be noted is that the new local education authorities have powers for raising further funds, some of which may well be used for the objects here advocated. Referring to the figures given in the early part of the paper, it may be again noted that the Federal contributions, corresponding to our Imperial contributions, to University education in the United States, amounted in 1900-1 to well over one million pounds sterling, whilst the State and Municipal contributions, with which the funds raised locally by the new education authorities may well be placed on a level, amounted for this particular purpose to another million pounds. Is it too much to ask that our new local authorities should rise to a sense of the very great importance to the country of education of a university standard, and should raise funds of proportionately similar magnitude for the same purposes amongst which engineering education occupies a prominent position.

Another question worth alluding to is whether or not we are too late to make up for lost ground. In one sense, of course, any attempt to retrieve the mistakes of a long period of neglect is never too late, but it may well be that if the period of neglect is allowed to continue too long the task of making up for the ground lost is well nigh hopeless. Such, however, in the opinion of the writer, is not the present position of higher engineering education in this country. The position attained by such education in the United States and Canada is one due to very recent expansion indeed. It is not quite correct to say that it is entirely the work of the last ten years, but the greater part of the development, and especially that which has caused a complete revolution in the attitude of employers towards these colleges, has taken place during that period. Ten years' leeway is not too much to hope to recover; but the work will be uphill and heavy, and every year's delay in starting it upon a thoroughly sound basis will add seriously to the difficulties of recovering the ground lost.

APPENDIX A.

COLLEGES, INSTITUTIONS AND SCHOOLS VISITED.

Columbia University, New York.
Brooklyn Polytechnic Institute.
Cooper Union, 9th Street, New York.
Pratt Institute, Brooklyn, New York.

Stevens Institute, Hoboken, New Jersey.
University of Pennyslvania, Philadelphia.
Drexel Institute, Philadelphia.
Girard College, Philadelphia.
The Central Manual Training School, Philadelphia.
The Johns Hopkins University, Baltimore.
The Normal and Industrial College, Milledgeville, Georgia.
The Military College, Milledgeville, Georgia.
The Manual Training High School, Indianapolis.
Purdue University, Lafayette, Indiana.
University of Illinois, Urbana, Illinois.
University of Wisconsin, Madison, Wisconsin.
University of Chicago.
The Manual Training School, Chicago.
Armour Institute, Chicago.
Lewis Institute, Chicago.
Northern Illinois College of Ophthalmology and Otology, Chicago.
University of Michigan, Ann Arbor, Michigan.
School of Practical Science, Toronto, Ontario.
Mechanics' Institute, Rochester, N.Y.
Cornell University, Ithaca, N.Y.
Sibley College, Cornell University.
McGill University, Montreal, Canada.
Worcester Polytechnic, Worcester, Massachusetts.
Clark University, Worcester, Massachusetts.
Peirce Hall, Harvard University, Cambridge, Massachusetts.
Massachusetts Institute of Technology, Boston.
The Waltham Horological School, Waltham, Massachusetts.
The Sheffield Scientific School, Yale University.
The New York Trades School, New York.

APPENDIX B.

MANUFACTURERS, EMPLOYERS AND PROFESSIONAL MEN INTERVIEWED.

(Teachers in Colleges, etc. excepted.)

T. C. Martin, Esq., Editor, *The Electrical Engineer*, New York.
R. W. Pope, Esq., Secretary, "American Institution of Electrical Engineers," New York.
J. A. Gayley, Esq., First Vice-President, U.S. Steel Corporation, New York.
J. J. Carty, Esq., Chief Engineer, New York Telephone Co.
E. H. Mullen, Esq., General Electric Co., New York.
The Spencer Optical Manufacturing Co., New York.
F. Wheeler, Esq., The G. F. Blake Manufacturing Co., New York.
Lamar Lyndon, Esq., Electrical Engineer, New York.
J. Carnegie, Esq., Engineer, American Steam Ship Line, New York.
C. Kirchhoff, Esq., Editor, *The Iron Age*, New York.
G. G. Ward, Esq., President, Commercial Cable Co., New York.

G. F. McMurtry, President, American Sheet Steel Corporation, New York.
Col. R. F. Crowley, President, Western Union Telegraph Co., New York.
T. F. Clark, Esq., Vice-President, Western Union Telegraph Co., New York.
J. C. Barclay, Esq., Electrical Engineer, Western Union Telegraph Co.
U. N. Bethell, Esq., General Manager, New York Telephone Co.
J. C. Rennard, Esq., Assistant Chief Engineer, New York Telephone Co.
W. F. Mosser & Son, Machinists, Allentown, Lehigh Valley, Pennsylvania.
Carl Hering, Esq., Electrical Engineer, Philadelphia.
Messrs. Olsen & Co., Machinists, Philadelphia.
The Baldwin Locomotive Works (A. L. Church, Esq.), Philadelphia.
Messrs. Wm. Sellars & Co., Testing Machine Manufacturers and Machinists, Philadelphia.
Messrs. W. Cramp & Sons (W. P. Smith, Esq.), Ship Builders, Philadelphia.
The New York Ship Building Co. (L. D. Lovekin, Esq.), Camden, New Jersey.
Prof. Brashear, Manufacturer of Telescopes and Optical Instruments, Allegheny, Pennsylvania.
— Dinkley, Esq., Superintendent, Carnegie Steel Works, Homestead, Pittsburg.
The Westinghouse Electrical and Manufacturing Co., East Pittsburg.
Chas. F. Scott, President, American Institution of Electrical Engineers, W. E. & M. Co., East Pittsburg.
Eugene W. Pargny, Esq., Manager, American Sheet Steel Corporation. Pittsburg.
— Davis, Esq., Superintendent, American Sheet Steel Corporation Works, Vandergrift, Pennsylvania.
Westinghouse Machine Co. (J. L. Hall, Esq.), East Pittsburg.
F. Holz, Esq., President, Cincinnati Milling Machine Co.
— Alter, Esq., American Tool Works Co., Cincinnati, Ohio.
— Cullen, Esq., Niles Tools Works, Hamilton, Ohio.
Edwin Reynolds, Esq., Chief Engineer, Allis-Chalmers Co., Milwaukee, Wisconsin.
Irvin Reynolds, Esq., Allis-Chalmers Co., Milwaukee.
— Neary, Esq., Messrs. Filer, Stowell & Co., Engineers, Milwaukee.
J. H. Warder, Esq., Secretary, Western Society of Engineers, Chicago.
— Cook, Esq., Western Union Telegraph Co., Chicago.
John P. Roche, Esq., Manager, Otis Elevator Co., Chicago.
— Cook, Esq., Automatic Electric Co., Chicago.
— Keith, Esq., Automatic Electric Co., Chicago.
W. W. Deane, Esq., The Kellog Switchboard & Supply Co., Telephone Engineers, Chicago.
Kempster P. Miller, Esq., The Kellog Switchboard & Supply Co., Telephone Engineers, Chicago.
G. A. Rogers, Esq., Editor, *The American Optician*, Chicago.
Messrs. Chambers, Innskeep & Co., Manufacturing Opticians, Chicago.

E. G. Acheson, Esq., Carborundum and Graphite Works, Niagara Falls.
H. W. Buck, Esq., Chief Engineer, Niagara Falls Power Station.
C. E. Acker, Esq., Manager, Acker's Alkali Works, Niagara Falls.
H. B. Alverson, Esq., Cataract and Conduit Co., Buffalo, N.Y.
Electric Light and Power Distribution Co., Buffalo, N.Y.
G. Eastman, Esq., Eastman Kodak Co., Rochester, N.Y.
The Bausch & Lomb Optical Co. (— Lomb, Esq.), Rochester, N.Y.
— Gleason, Esq., The Gleason Tool Works, Rochester, N.Y.
B. B. Clark, Esq., Optician, Rochester, N.Y.
S. S. Grant, Esq., Optician, Montreal, Canada.
C. P. Steinmetz, Esq., Electrician, General Electric Co.'s Works, Schenectady, N.Y.
A. L. Rohrer, Esq., Electrical Superintendent, General Electric Co.'s Works, Schenectady, N.Y.
E. J. Berg, Esq., Engineer, General Electric Co.'s Works, Schenectady, N.Y.
— Wells, Esq., American Optical Co., Southbridge, Massachusetts.
The Globe Optical Co., Boston, Massachusetts.
Professor Elihu Thomson, General Electric Co., Lynn, Massachusetts.
G. F. Blake Manufacturing Co. (G. D. Laval, Esq.), Manufacturers of Pumping Machinery, East Cambridge, Boston.
— Duncan, Esq., The American Watch Co., Waltham, Massachusetts.
Brown & Sharpe Manufacturing Co., Milling Machine and Tool Manufacturers, Providence, Rhode Island.
The Pratt & Whitney Co. (— Gordon, Esq.), Hartford, Connecticut.
The Hartford Machine Screw Co. (— Fairfield, Esq.), Hartford, Connecticut.
The New Haven Clock Co., New Haven, Connecticut.
The New England Watch Co. (C. B. Churchill, Esq.), Waterbury, Connecticut.
F. Boger, Esq., Editor, *The Optical Journal*, New York.
H G. Scott, Esq., Superintendent of Motive Power, The Manhattan Railway Co., New York.
The Metropolitan Railway Power Station, New York.
H. G. Wells, Esq., The New York Edison Electrical Co.
A. O. Benecke, Esq., The Western Electrical Instruments Works, Waverley, New Jersey.
The Crocker-Wheeler Co., Ampere, New Jersey.
Messrs. R. Hoe & Co., Printing Machinery Manufacturers, New York.
A. A. Hamerschlag, Esq., Consulting Engineer, New York.

The PRESIDENT: I have no doubt that Dr. Walmsley fully appreciates the applause with which you received his paper. The President.

Professor Armstrong has very kindly come here this evening to speak; he is not able to attend the next meeting, therefore, although the hour is late, I shall call upon him to address us.

Professor H. E. ARMSTRONG: I am sure, sir, I appreciate the compliment you have paid me; but I feel, at this late hour, it is impossible to deal properly with a subject of the magnitude laid before us in the able paper prepared by Dr. Walmsley. The amount of material which Professor Armstrong.

Professor Armstrong.

he has put before us for consideration is very large. Obviously he has dealt with it with the utmost care. Personally I find myself in agreement with a very great deal that is stated in the paper; at the same time, I feel very considerable difficulty in utilising it from the practical point of view of really gathering what, on the whole, his advice to us would be with regard to the use we are to make of the experience he has gained in America. I do trust that, if not at the next meeting, at all events on paper, you will hear the opinion of my colleague Professor Ayrton (who, unfortunately, has been very seriously ill and is still ill) on the special subject which interests this Institution; that you will have his views on electrical engineering education in America and on the facilities afforded there to teachers to keep in touch with the industry. I know that he has formed an extraordinarily high opinion of what is being done there to carry the industry forward. He is not so much satisfied with what is going on in the colleges, I believe, as he is satisfied with the wonderfully intimate connection which has been established between the employers on the one hand and the colleges on the other in training electrical engineers. He will be able to make it clear to you, I think, that the education is not confined to the college but is extended, in some cases, to the works in the most systematic manner possible. He is, I know, persuaded that we can learn a very great deal from American practice. I think he will have much to say also on a subject which Dr. Walmsley has touched upon, viz., as to what is done to give those who are engaged in the work of teaching the opportunity of keeping themselves abreast of the times. He will be able to confirm what Dr. Walmsley has said as to the colleges insisting that the man who is teaching shall maintain an active connection with the industry. I think the Americans begin to see that if, in the future, they are to get men for college purposes who are competent to do what, after all, is far the most important part of the work, viz., to teach, they must enable them in some way to get better pay than they can get as mere teachers; and that the only way of meeting the competition which practice affords is to give men full opportunity of practising professionally. I am not, of course, personally able to give an expert opinion on the technical questions raised with regard to engineering education. Dr. Walmsley seems to me to have dealt with the subject rather from the purely engineering side than from the electrical engineering side. No doubt you will have many speakers who will be able to criticise American work; but apart from what is being done on behalf of electricity—and it seems to me electricity stands in an altogether peculiar position at the present day; its advance has been so extraordinary; theory and practice are so intimately linked—I am not at all inclined myself to think that American college experience is going to be of very much use to us, except rather in teaching us what not to do than what to do. I came home well satisfied with what is being done here. I do not think that we have such an enormous amount of lee-way to make up. I think that if you take into account the work that has been done in this country in regard to electrical engineering education, if you take into account the extraordinary advance of opinion in regard to the value of educa-

Professor Armstrong.

tion among engineers generally of late years, as shown by the action taken by the Institution of Civil Engineers, for example, I think we stand on a fairly satisfactory footing; but I agree with Dr. Walmsley that we have not yet touched the employers. There, I think Professor Ayrton will tell you, is the great difference. There is no question that the captain of industry in the States does appreciate scientific assistance and that he means in the future to get all the scientific assistance he can and to make use of it to the very fullest possible extent. But the great question we have to discuss on a paper of this kind is whether the colleges are taking the right action in order to give him what he wants. I do not think they all are; I will say it absolutely in those words. It seems to me that the American colleges are behind us from the practical point of view, that they have scarcely emerged from the academic stage at present; that what we understand as technical education, the root ideas which have been so much developed by men prominently connected with your body, by my colleague, by my friend Professor Perry and by many others whom one could mention —that those ideas have not as yet established themselves firmly in America. It seems to me there is a lack of depth in a large part of the American training. I cannot quite understand Dr. Walmsley's position. He told us at an early period in his paper that because of the later age of entrance and also because their general education, as a rule, has been carried to a higher point, it follows that the candidate for entrance into the technical course in America is better equipped than he is in this country to take advantage of the training of the professional school. I think Dr. Walmsley subsequently altogether deprived that statement of its force, when he drew attention to the peculiar character of the college courses, to the way in which engineering was only entered upon in the third year, and to the fact that a large number of subjects was crowded into the third year's course. I am inclined to doubt altogether whether the average product which enters the colleges in America is in the least degree superior to the average product coming up to our colleges: it is a very difficult matter to decide upon. It would be necessary, I take it, to serve in one of the colleges for some time in order to be able to form a final opinion on the matter; but that is my impression, taking into account the character of the work that is going on. I think that our students are not inferior, except from one point of view, namely, that they do not put their backs into their work in the way in which the Americans do. I think that probably there are many explanations of this fact. The American school system is a different one from ours, and we must be very careful, when we are considering these questions, to distinguish between the education which the world gives and the education which the school gives. I cannot help thinking that the characteristics of the American are developed out of school rather than in school: that the extraordinary alertness which the American shows and his extraordinary receptivity are in no way bred in the school. My impression is that less is done in the schools to develop individuality than is being done in our best schools. My impression is that the American is over-taught throughout his college course; how he ever emerges from the college course with any indi-

Professor Armstrong.

viduality left in him I cannot quite understand. It seems to me that he is perpetually tutored from beginning to end. In England we are seeking to get away from that. Here we are seeking to throw the students more and more upon themselves. I see no evidence of that in America, except perhaps in the electrical industry. The teachers of electrical engineering are much newer to the work; they are not yet imbued with academic opinions to the same extent as their colleagues are, and therefore, perhaps, are ahead in developing individuality in their students. But as regards the training which is being given in the engineering colleges generally, I cannot help thinking that it partakes very largely of the character of high-school training rather than of true college training.

To pass to another subject, Dr. Walmsley has told us of the ample provision that is made for research. There may be a good deal of provision made for research, but there is not much evidence of research work being done. What the colleges are suffering from very largely is great over-provision of appliances, and under-provision of teachers and of well-prepared students. I think if, as one of the men referred to said, they scrapped the greater part of the provision and obtained teachers who could develop more individuality in the students, probably there would be a great improvement in the output. I think we shall have to watch very carefully the growth of opinion in America during the next few years with regard to the character of the output of the schools. There is a very great danger indeed that the product may not come up to expectation and that very serious injury may accrue to the schools in consequence. I greatly fear that the schools may be thrown back in public esteem in consequence of this happening. I know, as a matter of fact, already of several cases of the kind having arisen, of men having employed young fellows fresh from college to do work for them, and of their having been dissatisfied with the output; in consequence they have abandoned their scientific assistants. The mistake arose from their expecting too much, but this will be the tendency of employers. In a country like America I think there is a very real danger of that sort of thing happening. Without going at very much greater length than is at all possible at a meeting like this into the discussion, I think I have briefly made it quite clear that we have to deal with this subject in a very deliberate manner in availing ourselves of American experience. With regard to the wonderful provision of buildings and laboratories, to which our attention has been called, it is certainly very striking; but it must be borne in mind that after all a building is a monument—I think some of the buildings shown were erected more or less as monuments. Then, of course, there is something to be made out of buildings. A professor is not a monument and there is nothing to be made out of him, so that professors are not held in the same esteem as buildings; there is not the same reason for advocating the advancement of the one as there is of advocating the advancement of the other. Of course, colossal equipments also appeal to the public. I hope that before very long we shall very seriously discuss in this country the whole question of engineering college equipment and the use that is to be made of it. I had occasion

not long ago to write an article for the *Quarterly Review* on "The Reign of the Engineer," in which I put forward the opinion that it is very desirable that we should altogether modify the course of instruction, that we should throw a large part of the work we are now doing in the college on to the works; and that we should adopt the plan of training students from the research point of view—from the point of view of developing their thinking power and their originality—more than we have been in the habit of doing. If I may be allowed to say so in the presence of so many engineers, I have long thought that the engineer is not nearly sufficiently developed on the theoretical side; his tendency is, I think, to a very large extent to follow precedent. Certain dimensions are laid down for him; certain ways of doing things are laid down for him; therefore he is not inclined always to look at the matter from the research point of view; yet I venture to think that we shall have to consider the very great and grave questions of college equipment and training from that point of view. Before we determine to spend large sums on new buildings and on colossal equipments, I think we must make up our minds whether we do not need to modify the course of instruction to a very considerable extent. Professor Armstrong.

The PRESIDENT announced that the scrutineers reported the following candidates to have been duly elected:— The President.

Members.

John W. Jacomb-Hood. | George H. Oatway.

Associate Members.

Percival Storey. | Atlee H. Tracy.

Associates.

Walter Emmett. | Robert N. Mayne.
Ernest H. Lamb. | Edward W. L. Nicol.
John E. Williams.

The Four Hundred and Third Ordinary General Meeting of the Institution was held at the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, February 25, 1904—Mr. ROBERT KAYE GRAY, President, in the chair.

The minutes of the Ordinary General Meeting held on February 11, were taken as read, and signed by the President.

The names of new candidates for election into the Institution were taken as read, and it was ordered that these names should be suspended in the Library of the Institution.

The following list of transfers was published as having been approved by the Council :—

From the class of Associates to that of Associate Members—

Ernest Brook.	Guy Lyndon Drury.
Clifford Lakin-Smith.	Joseph McDermott.
Edwin Moorhouse.	Frank Powell.

Wilfred Lawson Winning.

From the class of Students to that of Associates—

Arthur Gregstone Shearer.

Messrs. J. T Morris and W. R. Rawlings were appointed scrutineers of the ballot for the election of new members.

The President announced that communications of sympathy, to which suitable replies had been sent, had been received from—

The American Institute of Electrical Engineers,
The Associazione Elettrotecnica Italiana,
The Société Internationale des Electriciens,

in reference to the death of Mr. McMillan.

Donations to the *Library* were announced as having been received since the last meeting from Messrs. C. S. Vesey Brown, Constable & Co., and E. Garcke; to the *Building Fund* from Messrs. P. Cardew, F. W. Clements, R. Rigg, F. P. Seager, and J. C. Smail; and to the *Benevolent Fund* from Messrs. P. Cardew, A. J. Ewing, and E. de M. Malan, to whom the thanks of the meeting were duly accorded.

RESUMED DISCUSSION ON PAPER ON "TRANSATLANTIC ENGINEERING SCHOOLS AND ENGINEERING," BY R. MULLINEUX WALMSLEY, D.Sc., F.R.S.E., MEMBER.

Major-General WEBBER, R.E., C.B.: Mr. President and gentlemen, in view of the very interesting discussion which we hope will follow on Professor Walmsley's paper, I shall only occupy your time for a very few minutes. Certain matters connected with secondary education are in the minds not only of those present, but also of those who will read the proceedings of our meeting. Last December a meeting was held, and the President and myself were appointed to represent this Institution at it; but owing to the President being unavoidably absent, I was there alone. I made a *résumé* of its proceedings. It was a Conference held at the Westminster Palace Hotel between a Consultative Committee and representatives of various scientific and commercial Institutions. The following were represented:—The General Medical Council, the Institute of Actuaries, the Institute of Bankers, the Institute of Chemistry, the Institution of Civil Engineers, the Institution of Electrical Engineers, the Institution of Mechanical Engineers, the Pharmaceutical Society, the Royal Institute of British Architects, and the Society of Accountants and Auditors. The Conference was held under the auspices of the Board of Education, and was opened by Lord Londonderry, the President. The objects of the Conference were to devise a system of leaving certificates, or certificates of general education and culture, at the close of the course of general education which is now growing and becoming more systematised in this country. The Consultative Committee were a very representative body. It comprised many gentlemen and one or two ladies whose names are well known in connection with education in this country. Sir William Hart Dyke, M.P., was the chairman. The Civil Service Commission was represented by Mr. J. Bonar, the War Office by Major-General Sir Henry Hildyard, and the Board of Education by the Hon. W. Bruce and Dr. Heath. The Board of Education particularly stipulated that their attitude towards the Conference should be defined as being one of being ready to consider carefully any scheme put before it, but that they were not to be regarded as committed to anything in the nature of an endorsement of the proposals that might be made. At the same time they expressed themselves as fully sensible of the injurious effects on secondary education of the present system. The Chairman also stated that it was not proposed on this occasion to formulate the discussion into resolutions. The need for such a scheme had become emphasised by the Act of 1902, under which Local Authorities had become interested in secondary education. The object is to get out of the existing system, which hampers all secondary education, and that all teachers in secondary schools shall have an object before them, with the view of establishing a standard of general culture, so that there will be only one or two qualifying and sufficient examinations at definite ages, directed and organised by Examining Authorities, for equalisation,

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assisted from one centre, the chief object being that all the professions shall if possible accept one "leaving examination."

The object in calling representatives together from those bodies of which I have given a list was that the Conference should endeavour to find out if unanimity in that respect could be attained. The representatives of the Professions were appealed to for their support of some such scheme, in order to overcome the difficulties to be met with in all educational directions. With such support it was felt that the Board of Edueation might hope, chiefly in the interests of the Professions themselves, to get more uniformity and less confusion than exists at present. The enquiry sought to ascertain from the various representatives present the extent of ground which the examinations for "leaving certificates" should cover. All present concurred generally in the view that the proposal to have one standard of leaving certificates of general culture is sound and likely to prove useful to the Professions. The words "one standard" does not mean, of course, that there should be one examination taken for the year, but that generally one standard should be recognised by all of those who had control of these examinations throughout the country. In the course of the discussion it came out that the Consultative Committee is opposed to the conduct of the examinations by means of papers set for the whole country, and, rather that they favour a standard of examination which shall be of a satisfactory character to some educational centre with which the school should be affiliated, and be simply an evidence that the boy or girl has passed through a satisfactory course of secondary education.

The question of how far the examinations can be unified was freely discussed, and very various opinions were elicited: generally, it was considered possible, that there should be a Central Board to represent all the examining bodies, whose duty it should be to co-ordinate and control the standard of the examinations. A cast-iron system by which the approval of the Central Board should be obtained on every examination paper before it was issued, was deprecated. This would be much simplified if the examination was confined to five or six subjects, and that all those of a technical nature were left for the subject of examination by the Professions themselves. It was suggested that the subjects should be Arithmetic, Dictation, English Grammar and Composition, English History (any period), Geography of the world, two of the three languages, Latin, French, and German, Algebra, including equations and fractions, and the First Book of Euclid. That was rather an extended list, but that list is even rather more extended in the case of the Students' Examination for entrance to the Civil Engineers. It was generally agreed that it would be useful if co-operation or consultation were established between the school teachers and the external examiners, but that the latter should be entirely independent as to the making and as to the award of the leaving certificate. Also that the result would be, that as boys and girls might have to leave secondary schools at ages varying between (say), 15 and 17, either for the professions, or for private life and enterprise, certificates, distinguished as "Senior" and "Junior," could be given, to be issued

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irrespective of age, at the discretion of the Governing Bodies. The subject is, of course, of interest to a certain extent in our discussion, because the whole foundation of what Professor Walmsley has been describing to us is based on the efficiency of the secondary education of the United States. We as an Institution, as you know, have had no examinations for our students, but we simply specify that they shall have been or are under training at Electrical Teaching Colleges, Government Schools, and so forth, and at present we have a very wide door of entrance for our students. In late years the Civil Engineers have for themselves narrowed that door, and they have established examinations for those who wish to become students under rules which you can all read. Their examinations are confined to elementary subjects, which include five compulsory and ten others, out of which two are voluntary. Several of those ten subjects are very important, and it is a question of how far you can expect more than two of them to be compulsory. In the discussion, the Civil Engineers were the body which laid more stress than the others on the necessity of holding their own examination. We who are their children in one sense—at any rate for 30 years we have had the gratuitous use of this splendid hall, and their assistance in many questions connected with the facilities that we have been able from time to time to offer our students—are desirous of following to a certain extent in the same path. But it seems to me that the suggestion that there should be a culture examination which we should accept, alongside, I mean, of the examinations of the great educational colleges which are now accepted by the Institution of Civil Engineers, and which comprise most of those in this country, is a good one—a culture certificate, obtained under the circumstances suggested at the Conference that we had in December. The question of conducting examinations, not only here but in various parts of the country (which is desirable), is a matter of expense, and my own personal opinion is that we should prefer to devote all the money that we can give to the help of our students in their examination, instruction, and career, after they have become students, during their career as students, and before they become associates or associate members of the Institution. I should like to add to the cast-iron list—*i.e.*, the list of subjects which every one would have to take up—one more subject. Do not think for one moment that I am making more than a passing reference to what has been going on in this country during the last year. I wish to quote the words of a very great and distinguished man—namely that we should have some course of instruction by means of which we shall be able to learn between the ages of 12 and 16, "to think Imperially." I think that expresses what I mean, it also expresses something which probably underlies what Dr. Walmsley has told us, that is to say, that the American youth is taught in his early years to think "Americanly," if it may be so called. It will be a stimulus which will enable us to join hands, not only here but with the educational institutions in all our great dependencies and colonies. It would also help to stimulate our students, in a knowledge not only of the commerce but of the geography, the ethnology, and the topography, and of all that appertains to the life of those

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colonies, and enable them to feel that we are subjects of one great empire.

Mr. Symons.

Mr. H. D. SYMONS (Student): Mr. President and gentlemen, I was not prepared to be called upon quite so soon. In the first place, I think we ought to thank you for inviting us students to take part in the discussion; it is a very great privilege which you have extended to us for this one meeting. I also wish to thank Dr. Walmsley very much for his paper, because it affects us very materially. The few remarks which I have to make are not from the point of view of any direct knowledge of the methods adopted in the United States, but more from the point of view which Dr. Walmsley's paper brings forward, viz., a comparison of the institutions there with those in this country. There is one point upon which I am sure there will be agreement, viz., that we cannot help noticing from the paper how many more opportunities an American student has of obtaining knowledge than an English student. Not only have their colleges finer and more modern laboratories, but they have also much finer libraries than there are in most of our colleges here, and a library is a very great help indeed to a student. I notice that the Massachusetts Institute have an arrangement by which lectures can be illustrated on an engineering scale, which of course is a very great advantage, because here very often in the middle of a lecture, the students have to troop to the laboratory to see some little point which the lecturer has to explain. With regard to the course of short lectures which seem to be arranged, I think there should be more of them in this country. The lectures are on special subjects, and are given by men eminent in the subjects lectured upon, and if they do nothing else they give the opportunity to the student of making the acquaintance of, and perhaps having some slight conversation with, men eminent in the particular branch lectured upon, and whom perhaps he would otherwise have only known by name. Then too, with regard to the college education, there is one thing which no college can do: it cannot give a man knowledge. No student can be given knowledge; it depends entirely on his own perseverance and energy in obtaining it. I think that is why a small class of American students who are unable to afford themselves a college education in their early years, but by hard work are able to do so later on, become such excellent students. It seems that this class of student corresponds very much to a small section of our own evening class students here who work very hard indeed. They are at business during the day, and either at an evening class or studying at home almost every minute of their spare time, both winter and summer. Although they cannot attain such positions as the day college students who have taken full advantage of the opportunities placed in their way, still they run them very close, and are a great deal in advance of many students who, instead of sticking to the home work, spend much of their time in amusements. Dr. Walmsley seems to question whether an American student can get through the vast amount of work which is expected from him in his fourth year. As students, I think we may say—and I think I am expressing the feeling of a great number present—that if a student has done his work conscientiously

and well up to the end of his third year, he ought to be able in his fourth year absolutely to romp through; because he does not have to think of the language which is used. When he starts learning, the student cannot understand what certain phrases mean, and it takes him some time to get hold of them; but once he understands them, and begins to think along engineering lines, the progress he can make is very rapid. I think the American colleges err in one point, where they endeavour to give a student his works training as well as his theoretical training. As students, we feel we cannot learn at college what we learn in works. First of all we cannot learn in the college, tact, which is a very great point in an engineer or a man who has to organise work, and more especially we cannot learn the control of men, which is a very essential point in an engineer's education. I should like to ask the author whether the American students form engineering societies amongst themselves; there is no mention of that fact in the paper. We have in almost every college in this country, both mechanical and electrical engineering societies, where the students read papers and hold discussions, as is done in the students' section of this Institution. The utility of these meetings, I think, cannot be too strongly emphasised; they are undoubtedly a very great benefit to the student. To get a student on his legs, to let him hear his own voice, and to permit interchange of ideas with other students, are important factors in the proper training of every student. I would like to refer to the attitude of the employer towards college students in America as compared with what occurs in this country. In America the only thing which seems to gain a position for a student is his knowledge. I am afraid that here we have a lingering affection for the student who has some influence with the management of a works, and who is therefor given a preference over another who, perhaps, has not that influence, but who may have somewhat higher technical qualifications. Mr. Symons.

Professor W. C. UNWIN: Mr. President and gentlemen, I have read the paper with very great interest. It contains a mass of information arranged in the most convenient way, such as I do not know that we could anywhere else put our hands upon. Now the general bearing of the paper is that we are very much behind in this country, and in fact, looking at the statistics alone, we are enormously behind the United States. I am not quite sure that that general effect of the paper is not an exaggerated one. We have to remember first—I am speaking entirely from memory—that the population of the United States is double the population of this country, and that the area of the United States is thirty times the area of Great Britain.* It has resulted from those two conditions that there has been an enormously rapid development of engineering work in the States, and an enormously large demand for young men who have some technical qualification. No doubt the special facilities for higher technical education are very much greater in the States than here; and through the generosity of men over there, very much larger expenditure has been incurred on the Professor Unwin.

* If our Colonies are included the Colonial Engineering Schools must be included, and they are on the scale of schools in the United States.

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equipment of technical colleges. But I am not quite sure that we are quite as much behind as the mere look of the figures would make us think. I heard from a man who has a good deal to do with the shipyards on the Clyde and the shipyards in the States, that though in the States he has entirely technically trained men on his staff, he prefers the staff which he has on the Clyde, where probably very few of the members of the staff have any considerable technical training. But there are ways of getting a technical education which are not represented by the figures of the numbers of students at colleges. In that connection I should like to refer to the table on page 401, which purports to give the number of students in colleges in this country. I cannot rebut it; but on the face of it it does appear to me that it cannot possibly represent fairly the number of students undergoing technical education in this country. I take, for instance, the third year's students studying engineering. We have at the Central Technical College just 100 third-year students studying engineering. I suppose that in other colleges in London there must be 100 more; that would make 200 for London; and that leaves only 147 third-year students for Manchester, Liverpool, Leeds, Bristol, Dundee, Glasgow, Edinburgh, Dublin, and the other colleges in Ireland, so that I cannot think that that figure is an accurate one. I do not want to quarrel with the paper in the least, but I am rather taking up points on which one feels a certain doubt. It is put rather strongly in the paper that the students who go to the American colleges are better trained than those who go to the colleges in England—that they come better prepared. In the first place there is a comparison of the entrance examinations. I have had a good deal of experience of examinations, and I do not know that there is a more difficult problem than to find out from the syllabus of an examination what the standard of the examination is. It does not even do to depend on the number of subjects in which there is an examination as very much indication. We have an entrance examination at the Central Technical College for instance, and we have limited it very strictly to the subjects which we feel to be necessary for students who are going to take up our course. I do not think it compares very badly with the examinations which Dr. Walmsley has given as the examinations at the American colleges; but there is another point. That examination by no means includes all the subjects in which our students might very well be examined at the time they enter college. I fancy that all of them could take various other subjects somewhat easily, and many of them would take some other subjects more easily than they take the subjects in which we examine them. Our examination is specially for our own purpose; if we wanted to adapt our examination to the kind of lads who come to us it would be a more extensive and a different one. My own feeling with regard to American colleges, is that, judging by our own students and by those I have seen in America, on the whole we get better students than they do in the American colleges—I mean students better prepared. I do not want to object to this paper, but what I would like to see in addition would be a much more detailed and critical examination of one or two colleges in order to see what the conditions previous to entering college, during college, and after

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leaving college, were, pursued not for a year or two, but to a somewhat later stage. I think in addition to the information we have in the paper we do want a somewhat more critical examination of the whole course of an American engineer's education. One word about a fourth-year course. I feel sure that at the end of the third year our students are more advanced than the American students at the end of their third year, but they have the advantage in America of a fourth year's course in all the better technical colleges; and I think the next step we have to take in the higher colleges of this country is to attach a fourth year's course to the third year's course, not for all students, but for the best students. It is not till you get to the fourth year that you can profitably specialise very much. But in the fourth year's course in America, there is the difficulty mentioned in the paper, that a crowd of engineering subjects has frequently to be taken, and in a comparatively short time the student is expected to cover a great amount of ground. Anyone who will consider the number of branches of engineering into which different students can go, and the amount of really valuable instruction which they might receive before they leave college, will see that it is quite hopeless to drag any students, however capable, through all that it would be desirable that they should know; and we must be content in the fourth year with a very considerable bifurcation, some students taking one subject and some another, and so introducing into the works knowledge of one or other of them, without each student pretending to know all. We want in the fourth year to specialise courses, a limited number of students taking each, and so to permeate the information, not all carried in one head, but carried one way or another, through many students into the works. It is conforming to the rule that an engineer should know something of everything and know one thing extremely well. Touching on the question of college workshops, about which I have, after many years, formed a strong opinion, I should like to say that the ordinary way of putting in opposition the college workshop and the factory workshop is really a mistaken point of view. No one could have been more opposed initially than I was—after an experience of a very badly managed workshop—to the idea that much good was to be obtained in college workshops. In the last twenty years I have changed my view very much indeed, and I would not now, under the conditions of technical training in England, be without the college workshop on any account whatever. It is in no way a workshop which takes the place of the factory training afterwards. We give no great amount of time to the workshop, but it is an enormous advantage to our students to be knocking about amongst tools, to be learning a little of their trade, getting new ideas about belts and gearing and all sorts of things, by touch and sight—by handling hot iron and so on—it is an enormous advantage, even though at the end of their college course we do not pretend that they are good mechanics. It has the further advantage that if you must take three years out of a lad's life for his academic training, he goes to the works at the end of it not wholly a novice; the foreman finds he can do something, and he gets on to instructive work very much earlier than he would if he had not done something at college. But I have not the slightest idea that the

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college workshop in any sort of way replaces the necessity of a workshop or office training afterwards. I should myself prefer, with the kind of students with whom I have to do—I do not lay down the rule for different branches of engineering, or for lads beginning from different standpoints and going to a different limit—but for such students that I have to do with, I should like a year's workshop training interposed between the second and third years, and I should like another year's workshop training at the end of the third academic year. There is one other point I would like to say a word about. A good deal is said in the paper on the subject of a student earning a living wage when he leaves college, and in America, to a certain extent at any rate, that is accomplished. I am not quite sure that it is even desirable, excepting in special cases, that a student who aims at being in some sense a professional engineer should be encouraged to enter engineering if he cannot support himself for five years. If he could take his college training and take a couple of years' practical work, he ought to be content to get his living wage at the end of that time. Engineering is not altogether an uncrowded and not altogether an easy profession. I have already occupied the time of the meeting for a considerable period; there are a great many things in this paper which one might remark upon; but I have just touched on two or three points which occurred to me at the moment.

Mr. Trotter.

Mr. A. P. TROTTER: Mr. President and gentlemen, I can only account for your calling upon me to take part in the discussion by the fact that I have the honour to be a member of the Board of Studies of the Electrical Engineering Section of the University of London. But how I got on to that Board, and why they keep me there, I cannot quite understand. I know but little of technical colleges, so that any remarks I make are said quite as an outsider and amateur. I notice that Prof. Unwin just now used the expression "technical training." I prefer that to the objectionable expression "technical education." I do not think it is education. Education ought to come first; then let a man study science after that. If you wish to give him the foundations of engineering you should give it him as science, as principles. The whole of the principles of electrical engineering are to be found in physics. Let a man get as much as he possibly can of specialised physics, and then he gets the foundation and the principles. The principles can be taught, and are of a certain educational value; that is rather a difficult question, and I will not enter into it. But the principles will always last. But if you begin to teach him designing, or how to wind armatures, or about all the different kinds of field magnets that have been made, and so forth, it may be very interesting at the time, as examples, but as knowledge I do not think it is of very much value, and as education, positively of none. The very information is bound to go out of date before he gets very far on in his profession. There are some things in which the teaching is abominable, for instance in dynamics. Just look at our text-books on dynamics! When an engineer has been at work for twenty years or so, and his algebra and text-book knowledge are somewhat rusty, he has to turn to books of reference if he wants to look up a thing. I confess that the other day

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I wanted to find out how to measure the acceleration of a train by the swing of a pendulum or spirit level. I thought I would find it out quicker from my books than by calculating it. I have a fairly good library, but not a single book gave me any help at all; they discussed *g*, and a lot of other stuff about falling bodies, so I had to work it out for myself. I wrote to a professor and asked him if I was right, and he put it quite clearly, but with a lot more algebra. This easily cancelled out, leaving the solution quite simple. Such things ought to be instinctive in engineers. Get these principles thoroughly in your head, and then all the details and applications will come naturally afterwards. I thoroughly agree with what Dr. Walmsley says on page 407 in this paper about the overloading and confused assortment of facts which is taught instead of principles.

Prof. Unwin has praised college workshops with rather faint praise. If he only intends to go as far as he has said, I am thoroughly with him. I quite agree with those uses which he claims for the workshop; but as he knows, and as we all know, it has been overdone a good deal in certain cases. I was the very first student of Prof. Stuart at Cambridge when his first workshops were started. I went to serve my time soon after that, and I had some discussions with him in the early eighties as to what a college workshop should be. I rather think, as Dr. Walmsley says, that the engineering laboratory will give a student a chance of seeing the scientific side of work, such as testing, which he probably will not see carried out in the same way in the works afterwards; he will also get some idea of the use of tools, and burn his fingers, and so forth; and if it is arranged as a training from a laboratory point of view chiefly, I think it will be of very great benefit. On page 413 Dr. Walmsley says that the Finsbury and the Central Colleges when they were opened were far in advance of anything which then existed in the United States, and a few lines further on he says they far surpassed anything there. I have not been to America, and I do not know very much about their technical colleges beyond what I have read, but there appear to be some things here which I do not think have been approached in America. For instance, Prof. Silvanus Thompson, for the lucidity of his writings and lectures; Prof. Ayrton, for his zeal and enthusiasm; and Prof. Perry for his fearless reforming of everybody and everything. They may have this sort of thing in America, but with all the shortcomings of our equipment we are fortunate in the enthusiasm of the teachers in our technical colleges. I wish more of them were present to-night.

I was in correspondence with some one the other day on the subject of education—in fact, about the Board of Studies at the London University. I got on the Board of Studies at the London University in this way: there are certain teachers on the Board, and "other persons." I am one of the "other persons." Sir W. Preece is one, Mr. Swinburne is one, and Mr. Mordey is one. This correspondent of mine wrote to me that "the preponderating voice in an Educational Board should be neither Teachers nor Experts, but the Users of the finished material turned out by the school, who are the brickmakers trying to mould and bake all sorts of

Mr. Trotter. clay into standard bricks, and stamp them as such with their hall-mark, quite irrespective of whether they are to be used for sewers or cornices. The User is the man who should have the say in the matter, and if teaching goes on as Educationalists seem to want it, all the bricks will be 'facing' and 'soft,' and there will not be any 'hard stocks' left for foundations."

I think there is a great deal in that, and I think it has a bearing upon this question why the American manufacturer seems to have openings, in fact, seems to be rather hungry for these products of the colleges. Of course none of our professors would admit that he cannot place out his men; still there does not seem to be quite a rush after third and fourth year students in this country. I do not profess to know anything about education; I am not a manufacturer; I am not one of those who use the material; and I cannot give you the answer to this very important question. Is it the manufacturer who is to blame? Of course everybody blames our manufacturers nowadays, the politicians and everybody; there is no such fool apparently as the English manufacturer. But is it his fault that he does not appreciate what you gentlemen turn out, or are you not turning out just that particular kind of brick which he wants? It is a vital question. It is rather interesting to see that the matriculation standard is so high in America. I like to see a distinction made, a distinction which is being lost in this country, between a University and a technical college. I think there is a very distinct difference to be made, and I am very sorry to see the London University abandoning the high standard which it had. Two Latin papers of three hours each used to contribute to that standard, and it was right to reduce them; but to throw over Latin as a compulsory matriculation subject is coming down to a position which is hardly that of a university. There is an immense scope and field for the technical college, as we have them here. But with regard to this work of instructing the student; to tell him all about the design and the details of his trade and a great mass of technical information is not educational, and it is very questionable how much of the actual details are going to remain useful in six or eight years, by the time he is in full swing with his work. I have mentioned once or twice the question of designing. I was making some inquiries on the subject, because as far as I can hear about it, much of the work of the electrical side of the technical college is devoted to dynamo designing. It is a subject which, no doubt, lends itself admirably to the lecture-room and to text-books; it is just the subject which I can imagine an enthusiastic professor dilating upon to a great extent. But I have asked manufacturers, Supposing a third or fourth year student was turned out from a technical college, having passed the very best possible examination in dynamo design, would you put him to that class of work? Of course not; there is a great deal more to be learnt by a dynamo designer before he can engage in the practical work of designing. I have discussed that subject with Continental experts. I was told by an engineer in Paris, who was interested in a large American firm, that his experience in Continental and American firms is that the larger the firm the more specialisation

takes place. An American manufacturer will have a man who can design tramway motors and will keep him down to that one particular branch, and would not expect him to design lift motors. A man who becomes such a specialist can do hardly anything else, but he does that one thing uncommonly well. I am told that the practice is that first of all the electrician of the firm says what he wants designed, and he describes pretty well what the dynamo or motor he requires must do. Those requirements are handed over to a mathematician, who gets out the windings and calculates all the interesting things which the professors teach you so much about. He gets those out, and hands them back to the electrician to see if he has grasped what he asked him to do. Probably he did not. Well, when those two have settled it, do they build the machine? No! They pass it over to a mechanical engineer, who with his draughtsmen gets out the drawings and designs the machine to suit what these other two gentlemen want. If there is a technical head of the firm, he will look over the whole thing and see that it is satisfactory. I asked—supposing the mechanical engineer were ill or away, could not these other two men do it? No, they could not be trusted! I was told of an eminent mathematical electrician who designed a dynamo; the result was magnificent, but it was not engineering. You cannot begin to teach a man to specialise in that way in college; it would be folly to do so; but that specialisation comes on in after-life. The whole point of the thing is that this so-called technical education—I prefer to call it technological instruction or some word of that sort—should be devoted very much more to the general principles of the science which, if properly learned, a man of ability can apply in a practical way afterwards. Mr. Trotter

Professor J. D. CORMACK: There is very much in this valuable paper that I would like to discuss, but I will limit my remarks to a few minutes. I think all the members of the Institution will agree with me that Dr. Walmsley could not have read this paper to a more suitable Institution than the Institution of Electrical Engineers, for especially in electrical engineering are science and practice intimately bound together. The paper enables us to measure our system against the American system, and the tables are valuable for comparative purposes. There is no doubt that Americans believe in education, and some remarks made recently by an American visitor to this country seem to indicate that the belief is very strong. He inspected the scientific department of one of our well-known colleges, and before his departure said, "Well, we believe in education in America. We may be wrong; but if we are right, God help England!" They not only believe in education, but they have made it their special study for some considerable time, and they are ready to back their faith by money from public and from private coffers. Professor Cormack.

Dr. Walmsley has traced the career of the engineering student from the secondary school. Any reformation that is going to take place in this country in the methods of engineering training must take account of the training in secondary schools. A comparison of the syllabuses of the entrance examinations of American colleges and of our own colleges does not show any very great difference. The standard they

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expect is, I think, no higher than the standard we ought to expect in this country from a lad of the same age—18 years. I do not say that we always get it, because I do not think that secondary schools have yet realised that engineering is really one of the learned professions, and that the training of the boy who is to become an engineer ought to be as carefully looked after as the training of a boy who intends to enter—I was going to say one of the more learned professions, but I will say one of the *other* learned professions. In this connection one hears very often now of the formation of engineering courses in secondary schools; and if the courses are on the right lines we cannot but welcome them. Sometimes with a great flourish of trumpets the foundation of a workshop is announced. A workshop is good in its own way, but I venture to say that its place is behind mathematics, mechanics, physics, and chemistry, and that any time devoted to it should not be deducted from the time devoted to these fundamental subjects. The fact that there is an engineering workshop in a school is not a guarantee that a suitable preliminary training is being given in the school. It would be well if parents realised that a boy will not necessarily make a good engineer because he can use his hands, and that brains are necessary in the engineering profession.

In comparing our college courses with the American courses, the first striking difference is the fourth year in the American colleges. The syllabuses show that in the first year a portion of the time is devoted to languages and literary subjects generally, and also a very considerable proportion of the whole time is devoted to workshop practice. If the college training is to precede the works training I think something might be said for workshops in colleges. It certainly does give the student opportunities of becoming acquainted with tools and machines; but if the better system of training is the "sandwich" system, or one of its modifications, then I think there is no necessity for the workshop in the college, and the time saved might be devoted to the engineering laboratory or to other subjects. If there is no workshop in the college, and if we have a sufficiently high standard of training at entrance to the colleges, I do not see that there is any reason why, in a three years' course, we should not be able to produce a student who is thoroughly grounded in principles. I am quite in agreement with Mr. Trotter when he says that the teaching of principles is the most important part of college work. Sound principles form the basis of real progress. Practice is changing, especially rapidly in electrical engineering. What may be taught as current practice in the college one day is very old in a few years time, and students must be provided with tools with which to tackle new problems.

Another feature of American colleges is the splendid engineering laboratory equipment. Dr. Walmsley, however, tells us somewhere in his paper that the laboratory is not made full use of, that it is only used in the third or last year, little time being apparently devoted to it. In that respect I think we are distinctly ahead of the American colleges here, because the experimental side of the subject is always carefully looked after during the whole three years of the students' training. The paper points out that an important

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part of the fourth year's work is the preparation of the graduation thesis. I think that is a most excellent training. It draws out the student, it compels him to think for himself, to marshal his facts, to look up references, to compare the work that has been done by other people on the same subject, and altogether it is very valuable as a training, even if the thesis itself cannot be regarded as a considerable contribution to existing knowledge. In this country little is done in writing theses, probably too little. There are reasons, no doubt. The time available is short, and there is generally an insufficiency of laboratory equipment and staff. To make the greatest use of colleges in this country there must be co-operation between the employer and the colleges, and the colleges must have financial assistance. The employers must say what kind of "bricks" the colleges ought to make for them, and the colleges will then have a chance of turning out a suitable article. The employers must also be looked to for an opinion as to what is the most suitable scheme for the training of an engineer. This subject has been much in evidence lately, and I hope the Committee which the Institution of Civil Engineers has appointed to investigate the question may arrive at some more or less general decision as to a suitable training. When the colleges have before them a scheme which is approved by manufacturers and engineers generally, I think there is no doubt that they will put themselves in line with the scheme, and carry it through with the necessary financial assistance. In the provinces considerable sums of money have recently been expended on engineering departments in colleges. Glasgow, Birmingham, Liverpool, Manchester, and other provincial cities have all spent large sums, and it is to be hoped that London will not fall behind the provinces. There is no doubt that the employers hold the key of the situation, and I trust that the present general interest in the subject will not subside until some permanent good has resulted.

Dr. Glazebrook.

Dr. R. T. GLAZEBROOK: Mr. President and gentlemen, I do not know that I ought to interpose at this stage of the proceedings with any remarks, because in my present work I am not very specially connected with engineering education; and though I hope I have done something in the past in teaching and in instilling those principles on which I think with Mr. Trotter the whole of engineering education is based, yet there are others in this room who are at the present moment much more intimately connected than I am with the direct application of those principles, either as teachers, as employers, or as students. Still, sir, I value the opportunity which you have given me of expressing my appreciation of the paper that Dr. Walmsley has laid before us, of stating my views as to its importance and its interest, and as to the value of the enormous amount of labour and work he has spent in compiling these various statistics. With the conclusions of the paper I do not think I have any very serious difference. They are stated in brief on page 410, and I should like to address myself to the two main points there mentioned. Dr. Walmsley there states the first point, viz., "The lack by many of our leading manufacturers of support and encouragement of the work of the colleges, either by offering positions to the best college graduates," and so on. I think Mr. Trotter and Professor

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Cormack have both drawn attention to a very important matter in connection with that alleged deficiency. Is the deficiency really in the manufacturers, or does it lie, to use the simile that Mr. Trotter employed, in the bricks that are being provided for their use? A great deal more inquiry, I think, is needed on that point; and, as Professor Cormack has said, one must hope that the inquiries which are going on now, and the work of the Committee which has lately been appointed by the Institution of Civil Engineers to inquire among manufacturers and others, will lead to some very definite result. Some few years ago, when I was at Liverpool, I met with very much the same difficulty in an attempt that was then made to establish a school of commercial education. I found that a very large number of the prominent merchants of the town preferred to take their clerks and boys quite young, and to put them through the drudgery—for it was drudgery—of the office from the very beginning, rather than have the more finished product which we hoped at University College we were producing in our school of commercial education, men who looked forward to having a rather better position when first they went into the office. I take it there may be a good deal of that same kind of feeling among engineers that there was among merchants and others. It is of great importance to discover whether that feeling is a right and proper one, and why it is that it exists. For myself I cannot think that it is a right and proper one. Mr. Trotter has said that of course no professor will admit that he does not find it possible to place his students; still I think from my own experience, knowing as I do a large number of gentlemen who are directly interested in engineering education as professors and teachers, that the claim they make is a true one, and that even now places can be found for really well-qualified students after they have passed through the course at our universities and university colleges.

When one looks at the array of figures that is represented on the wall or in the paper, and realises the enormous sums of money that are spent or have been spent in America on educational matters and in some measure on engineering or technical education or work, it makes one feel jealous to a certain extent, but at the same time it raises a very important question. Admit for a moment that we are distinctly behind our American cousins in this work: is it really necessary for us to spend sums comparable with those indicated in order to overtake them and to put ourselves in the way to enable our young men to take their proper positions and profit by the education that can be offered them? Is it necessary that our technical colleges and our university colleges should be fitted in the extremely elaborate manner that is described in this paper, and that their laboratories and museums should be so complete? I confess, sir, that sometimes it appears to me that a very completely fitted engineering laboratory may tend, and does tend, to become somewhat of a museum, and that the elaboration of the apparatus sometimes defeats its own object. For my part I should prefer to try and teach my students, whether teaching them physics or engineering, with somewhat simpler means and simpler apparatus; and I am not clear that it is at all necessary even to suppose that we must fit up everywhere

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laboratories and museums on the same kind of colossal scale that has been followed in America. No doubt the best method of teaching—we cannot adopt it in all cases for want of time—is to set a man to solve some simple problem for himself. That, I think, can be done in many cases, perhaps best with fourth-year students, if there are fourth-year students, but in many cases with very much simpler apparatus and less expensive means than it appears are provided in many of the American colleges. Mr. Trotter referred just now to his early training at Cambridge in Professor Stuart's workshop. My mind goes back to my early days, some thirty years ago, in the Cavendish Laboratory, where the teaching in those days was not specially organised, but where we had a professor of immense power and unbounded enthusiasm, who would set us on a problem and leave us pretty much to ourselves to work that problem out, ready to give help whenever we wanted it and whenever we went to him for it, but by no means ready to spoon-feed us continuously every day, or to set us to pass on from one experiment to another through a course, very carefully arranged, in great detail, down to its smallest points. Such a method seems to me the right one to adopt whenever practicable. I had during the summer some interesting conversation with a very distinguished American meteorologist who was here in England at the time, and who was comparing, much to our disadvantage, the sums that the Government here can find for the most important work of the Meteorological Office, with those which were at their disposal in America for a like work. He told me that during the past fourteen years, I think, on no occasion had the Government authority—Congress—reduced in any way the estimates put before them for meteorological service, and that on several occasions the estimates had been sent back because sufficient had not been provided for certain points which Congress thought important. But he went on to say "the real discovery in meteorology will not come from us in America; it will come from you here in England. Your method of teaching, your method of training the men, is in so many respects superior, that I believe the discovery which is now wanted will be made here; but I believe we shall use it when it is made, and we shall turn it into money value." And I am inclined to think there is still some hope for us in the same way on the engineering side, even though it may not be possible for us to spend the immense sums that are mentioned in this paper; and while my thanks individually are due to the author for what he has put before us in the paper, I cannot help regretting with Mr. Trotter that he has not taken a rather more sanguine view of what it might be possible for us to do here at home.

Mr. Harrison.

Mr. H. E. HARRISON: Mr. President and gentlemen, no doubt with the laudable purpose of stimulating us to our utmost, Dr. Walmsley has made out the case of England as bad as it can be. According to him, we have ten years' leeway to make up, and to effect this, we must first of all get a gift of somewhere about £10,000,000 to equip technical institutions, and then an additional gift of the interest on about another £10,000,000 to endow these institutions; so that apparently very little can be done unless we can get pretty quickly some £20,000,000. Now, in suggesting

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that this is what we have to do, I think Dr. Walmsley has entirely overlooked what has been done in this country by unendowed institutions. It is known to most of you that some fifteen years ago your present Treasurer, with the assistance of half a dozen friends, established a training institution, which is wholly unendowed. What has been the result? The Board of Control have been enabled to pay all outgoings, and by a certain self-denying ordinance they have established a fund out of which a new, and I hope much better, Faraday House is now being built in Southampton Row. The idea that the parents, at all events in this country, of those who are about to become engineers wish somebody else to pay for their training is, I think, a fallacy, so that as far as the £10,000,000 said to be needed for endowment purposes, it is not necessary. Of course the question of money for the equipment of institutions, which is undoubtedly much wanted, is a very different matter. You can ask a man to pay for his son's education, but you cannot ask him to equip a school for the purpose, and certainly if, as Dr. Glazebrook has pointed out, the equipments in this country ought to be on the scale of those which exist in America, the case would be hopeless; but I do not believe that it is at all necessary. It is some years since I was practically engaged in engineering; but I doubt very much if the essentials of a good engineer have changed very much since my time. A good engineer was then the man who could get the most out of the material at his disposal. For that purpose it is the worst possible training to give the student, at the start, elaborate apparatus, for he is certainly not going to get elaborate results. On the contrary he should start with the simplest possible; then having been taught to get the best possible results out of it, he should pass on to the plant actually used in factories. But again, such plant need not be found in the training institutions. What, I think, should be done is what has been done in the institution to which I have referred: suitable arrangements should be entered into with such firms as Willans and Robinson, Belliss and Morcom, and others of this type, by which the student, having passed through his college course, is enabled to put into practice what he has there learned, with the enormous plant which is placed at his disposal—obviously under certain restrictions. To conclude, I do not take the pessimistic view of Dr. Walmsley. That a great amount has to be done there is no question, but at all events I think that, instead of waiting for the £20,000,000, we should induce people in other cities to follow the example of our Treasurer by founding self-supporting institutions, making use of the enormous plant which already exists in English factories in the way I have indicated. Personally I think that indiscriminate endowment is just as bad as indiscriminate charity. It seems to me wrong in principle that the ordinary middle-class parent, who is perfectly well able to educate his son, should look to somebody else to pay for about two-thirds of his education. That is bad enough, but worse still, the waster who simply idles away his time at college gets just as much paid towards his professional education from endowment as the really able and industrious student. If benefactors will give, if we get any of the

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second £10,000,000, it seems to me it should be applied not in indiscriminate endowment, but in the foundation of scholarships and exhibitions which should be awarded to brilliant students by examination and by nomination to the merely capable and industrious.

Mr. Cooper.

Mr. W. R. COOPER: Dr. Walmsley's paper raises two main questions. The first is: Is the product that is being produced by the colleges a good one? And, secondly: Should we follow the school-teaching of America? With regard to the first, the schools turn out something which naturally they consider is good. But speaking as an old student, I remember that employers used to be rather indifferent to the value of college training. I think this attitude was due to some extent to a false idea which students are liable to get—I do not know how—that when they leave a technical college their training is complete. Of course it is by no means so; but until employers will express their views on this subject and join with the professors, I do not see that very much can be done. I am very sorry to see that employers this evening are taking no part in this discussion, as if the subject were of no importance to them. If the employers would meet the professors, and clearly understand that students must finish their training under the employers, and that facilities must be given to students for that purpose, I think something of value would be done. Of course we all know that students can get certain facilities by paying a premium. The facilities are that they are allowed to pick up what they can get, and unfortunately they often miss what they ought to pick up, simply because they do not know it is worth attention. On the other hand, colleges must recognise that students cannot study everything in the college. Probably that is recognised by the colleges, but it is not recognised by the parents. There is one great difficulty in the course at a college, namely, that the branches of engineering are becoming more and more numerous, and yet a college training has to suit a man to enter any one of those branches.

It has always seemed to me that something might be done by obtaining information from students after they have left the college and gone into practical work. It is difficult for the professors to get at the employers and know exactly how their students are getting on, and so they do not quite know how the employers feel about them; but if a student does not know what he should know on entering work, he soon becomes painfully aware of the fact, and he would have no objection to telling the professors why it is he is not getting on. Of course that may sound rather like teaching our grandparents, but I do not think this is a serious objection. No doubt every criticism so obtained would not be of value, because there are always a certain number of men who never get on, whatever their training. But, on the other hand, I do think that some very useful information might be obtained, only it must be obtained from students in their first year of practical work, otherwise their initial difficulties are forgotten.

With regard to the second question, as to whether we should copy the methods of the United States, I think we ought to be very sure of the conditions. Are the conditions in this country the same as those in

Mr. Cooper. America? I rather doubt if they are. In the States, apparently, a four years' course takes the place of three years over here; but the students seem to enter with much poorer preparation, and, besides that, they get very much more time for college shop-work. But it is quite impossible to take the place of commercial workshops by means of college workshops, for the obvious reason that they are not commercial. In commercial shops there is not only the value of seeing work done, but the student comes into contact with the British workman, and it is a very great thing to see the ideas of the British workman. and to see something of his human nature. Then as to extending the three years' course to four years, in any case I think that would be a mistake. First of all, there is one great factor which is never introduced into a technical college, and I do not see how it could be introduced, namely, the factor of £ s. d. Engineers not only have to design works so that they will work, but they have to design them so that they will pay a dividend as well; and therefore work outside a college is quite different from what it is within. There is another important point, namely, that students working in a technical college work without responsibility. When a man knows that if he makes a mistake he is liable to lose his position he works with a greater stimulus.

Mr. Buckmaster. Mr. C. A. BUCKMASTER: I should like, sir, with your permission, to make a few remarks on the discussion; because it is of very great interest to one who, like myself, is a Government official connected with education to know what are the views of the various parties to this controversy, as to the proper training of engineers, because it really is a controversy. Dr. Walmsley's paper will be for a long time to come a sort of mine into which each of us will dig for our own particular set of arguments. But what strikes me as most characteristic of this discussion is that after all these years we still do not understand each other's terminology. Nothing is more marked than to see the difference shown, for instance, by Mr. Trotter and Prof. Unwin as to the relative values to be attached to the workshop attached to a technical college. As a matter of fact, the technical college in this country hardly yet realises what it is intended to do, and what it can do. It has been led away very often into trying to make itself a more or less inferior copy of some University; and I feel sure that the training of engineers is often confounded, very much to the disadvantage of the training, with obtaining a degree in engineering. And the result of this copying of the University, however good it may be for the mental development of the individual, is not necessarily a good thing for the training of the engineer; because, as Universities are organised in this country, they lack almost entirely that elasticity which is so marked in Germany, by which the student who has obtained a certain amount of thorough preliminary training can specialise in any branch, or in any part of the whole science which he feels particularly called to investigate. Unfortunately a person in this country who requires a University degree has to take a particular course which is drawn up, with more or less skill, to meet what are considered, not the wants of the individual, but the more general wants of the great bulk of the

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body of students; with the result, of course, that we at once cease to secure that specialisation, which it is the duty of the technical schools to foster. This confusion between the technical college and the University is an extremely common one. I take it that the post-graduates and the special courses in these American colleges represent very largely what we wish to see in a great many of the technical institutions of this country, so that men who have received a good sound general training, an engineering training if you like, so far as the University understands the term, may then specialise in a technical college, which should be intimately in touch with the employer, which should know what the employer wants, which should have employers on its Council, which should, in fact, be run more or less by the employers, but which should have at its command the finest talent that it is possible to secure in any particular line the engineer in that part of the country requires. General Webber stated that the training in secondary schools has a very important bearing on the matter. I may say that I watch with considerable alarm the fear that we shall add another more or less stereotyped examination to the crowd of examinations that we already have, and call it a "Leaving Certificate Examination." So far as the functions of any central body are concerned, I am quite sure it should not be an examining body of that character, but should see that the standard of attainment in a school is sufficiently high to be suitably described as a thorough secondary education. The particular subjects that should be taken up should vary from school to school, from one part of the country to the other. All that is needed is not to make a list of subjects which should be compulsory, with one or two more that should be optional, but to see that those subjects that are taken are taken to a sufficiently high standard, so that the person who has gone through them has had a good sound secondary education. I think, so far as regards the future training of engineers, most employers, and I hope most professors too, would say that they should require from the secondary schools the power of calculation, the power of expression, the power of observation, and the power of drawing. If they can get those things, the secondary school will have done its duty. There is one other point I should like to refer to before I sit down, namely, the fact that the technical colleges in this country have to deal with such very imperfect material. They really perform, so far as they can do it with the limited means at their disposal, the functions of half a dozen different institutions; and it is impossible to say, dealing with merely their day work alone, how far they are covering the ground required. I was glad to hear mention made by Mr. Symons that many students do work in the evening. One speaker mentioned a friend of his on the Clyde who preferred to have men without college training to those with it. But I should like to point out, from an intimate knowledge of the Clyde for many years, that it is the rarest possible thing not to find in any works on the Clyde many men who have attended the evening schools in Glasgow, who have gained by sheer hard work after the day a great deal of the knowledge which is applied in the shipyards, and which has made the Clyde one of the finest schools of naval architecture in the country.

Dr. Fleming.

Dr. J. A. FLEMING: I came prepared with a number of statistics on the subject of electrical and mechanical engineering in London, but I feel, at this late hour of the evening, that the meeting will be grateful to me if I spare them as far as possible the infliction of all these figures. There is one remark I should like to make, however, which concerns the special work of engineering education in London. Dr. Walmsley has given us an immense mass of useful information in his paper, which it will take a long time to digest, and no one can deal with more than one or two points in his extensive and valuable remarks. The whole interest of the matter under discussion as regards ourselves, I think, really centres round the question how we stand nationally with regard to engineering education as compared with America and the Continent. With regard to the provinces of England, I am confident that we shall be able to hold our own. In the young but vigorous universities that are growing up at Birmingham, Manchester, Liverpool, and elsewhere, I feel sure that this problem will be satisfactorily solved. But London offers very peculiar conditions. London is a very large place, and, moreover, we in London suffer a great deal, I think, from what we may call the want of local patriotism. A man is proud of being a Birmingham man, or a Liverpool man, or a Manchester man, and he will do something, and often great things, for the educational interests of the town in which he has lived and made his money; but no Londoner will do anything specially for St. Pancras, or Finsbury, or the Strand, because he lives and prospers in these great boroughs which are the size of provincial cities. As regards the position in London, I have been in correspondence with the Principals and Professors in different colleges recently gathering statistics. Without going into details, I may simply say that there are at the present time twelve institutions in London, in which there are fairly well equipped engineering laboratories, and in which regular courses of teaching are being given in the daytime. There are many more Polytechnics and Institutions of that rank in which there are large classes in the evening; but, leaving out the evening work, I find there are between twelve hundred and thirteen hundred students taking regular instruction in mechanical and electrical engineering courses in London in twelve colleges. Of course the evening classes are vastly larger. There are altogether about five thousand students in those classes studying various separate portions of the subject. Altogether in London we have a grand total of over six thousand engineering students. As regards the courses, we do not, I believe, compare unfavourably with the Continent. People often talk of Charlottenberg with its five thousand students; but as a matter of fact in the years 1902–3 there were eighteen hundred students in Charlottenberg taking the regular course of mechanical and electrical engineering, and, therefore, so far as the mere numbers are concerned, I do not think we compare unfavourably. But what we do lack considerably is a coherence and a specialisation in our teaching. There is a great waste of teaching power because we are so unorganised. We have numerous institutions, in each of which we have professors of mechanical and electrical engineering, and although each institution may be organised in itself, they are not organised as a whole taken

together. In the present state of engineering it is ridiculous to talk of one man teaching electrical engineering; it needs a dozen specialists to teach it properly. Therefore nothing can be done until we have greater coherence between those institutions. No doubt it is a very difficult problem to weld them together. People talk about gathering together all these separate departments in one well-organised college of engineering. In each of these different colleges the engineering branches have taken very deep root, and they are often valuable assets. For instance, at University College the gross fees paid by the students in all departments amount to about £17,000 a year, and of that amount one quarter is contributed by the Engineering Department alone. Therefore if we were to remove these different engineering faculties, and dump them all down, say, at South Kensington, we should leave behind, in a financial sense, very large holes in the colleges which would require to be filled up in some way or other. It is easy to talk about the collection of these departments in one Central Engineering Institution, but it will not be easy to carry it out. The alternative to that process is to assist the existing institutions. But there are great obstacles also to this, arising from want of space for extension, even if the question of providing means can be overcome. Moreover, we should not then overcome the objections arising from the absence of proper specialisation in the teaching. But, above all things, I think that whatever is done should be done by the teachers and those who have had experience in the matter, and not by mere politicians. We are all agreed that it is the man behind the gun as much as the gun itself that is effective. On the other hand, it is not simply a question of apparatus. You may stock big buildings from garret to cellar with apparatus, and yet not produce the kind of teaching required. The only way in which that can properly be worked out is by letting it grow up from that which already exists. At this late hour of the evening I must not detain you with more remarks, although it is an exceedingly interesting subject. I should like to congratulate Dr. Walmsley very much indeed upon the mass of information he has gathered together, and venture to hope that his paper will be a means of stimulating further interest in this important question of engineering education. Dr. Fleming.

Mr. W. J. LINEHAM: Mr. President and gentlemen, at this late hour my remarks will have to be of a very general character. Major-General Webber asked us to think Imperially. I wonder how much Imperial thinking we have been doing to-night. It has been very largely British I agree, but Imperial, no. Dr. Walmsley's American visit was indeed a colossal work, and his paper is a thoughtful and masterly production. He deserves the thanks not only of this Institution but of future generations of engineers. I wonder, however, if we shall be able to modify our national characteristics so far as to accept and profit by the lessons he has brought from America. England has been a pioneer of education as of many other things, but she has without doubt been distanced firstly in Europe, and now in America, on lines which she herself laid out to begin with. This is not the fault of the schools themselves, but of those whose duty it is to support Mr. Lineham.

Mr. Lineham.

them. Danton said, "After bread—education," which is only the same thing as saying that there is nothing of value in the economy of the world but education. Everything depends upon it, and the country that does not spend every possible penny of its public and private funds upon education, either sleeps or deteriorates. And when we hear of such lavish expenditure in the States upon college workshops, laboratories, power-houses, and electrical tests, by means of money which has come from the State, the millionaire, and (mainly) from those who are not millionaires, we conclude that America has largely learnt the lesson that we have been slow to learn, or rather that we have not yet decided to learn fully. Surely the most important matter is that there should be expenditure, immense expenditure, an expenditure hitherto undreamt of, and which must be given without stint to this greatest cause of education, and especially to that most useful and applied form of it known as technical education. What is the good of repeating that "knowledge is power," if we show by our actions that we doubt it? While discussing and re-discussing the particular way in which the engineering student should imbibe his education: whether he should take his practice first and his theory afterwards, or his theory first and his practice afterwards, or should take them simultaneously, we are apt to forget our main objects—that his theory and practice should have correct proportions only, and that he must be assisted to an immense extent by the State, the municipality, and by the money of private individuals altogether. It is not of the first importance that the theory should be taught before breakfast or after dinner, as the case may be, or should be taught all the time and the practice therefore left till finer weather; but it is important that the pupil should have theory and practice both. And yet, though these statements may appear gratuitous and unnecessary, it must not be believed that the fight for a perfect and all-round engineering education is complete. Employers have for too long looked severely askance at the effects of engineering teachers, and have been too apt to condemn rather than assist. At last some of the English firms are beginning to realise that they are to get a large amount of salvation from the schools, but the old ideas are by no means completely scotched, as will be found on referring to Professor Goodman's remarks before the Institution of Mechanical Engineers at its last summer meeting. (Professor Goodman mentioned that the manager of one of the largest Leeds firms had said that, "Young engineers did not require the Yorkshire College, they needed merely to get a 'Molesworth.'") Let it not be supposed that I want to dignify the schools at the expense of the works, for nothing in this paper has pleased me so much as the statement that American manufacturers, while welcoming the diplomés of the colleges, were disposed to test these products in actual life, and not take them for granted. No one with a grain of educational sense would put an examination result down as a true test of education. But a testing by their fruits is all that any good school demands; it is the rejection of school work without a fair trial that rouses our sense of injustice. Referring now to the individual parts of the paper, I was surprised to find that such high fees were demanded of American students, and that

the entrance age was such that the pupils emerged from college at twenty-two without having had a scrap of commercial practice or a particle of earned money—arrangements which I think are open to considerable improvement. The finest polytechnics of Switzerland, such as that of Zurich, and I daresay many others on the Continent, take students at merely nominal fees. The question of men for the college staff is of the most intense and urgent importance in all countries, and if it is an unsolved question in America, it is none the less so here. Only that in England commercial salaries are lower, and the comparisons between England and America are not so much to the disadvantage of the former as would at first sight appear. Nevertheless, the salaries of technical teachers in England are not such as to attract men who are at once successful practical engineers, and thoroughly able teachers. This raises a point which must not be overlooked; success in practice by no means necessarily bespeaks the successful teacher; for teaching must have its training as its long experience every bit as much as engineering practice, if it is to be successful; and students will soon leave a bad teacher severely alone, however eminent he may otherwise be. On the other hand, that engineering teachers should be compelled to practise is a self-evident requirement if their teaching is to have its true value; but over-consultation must be guarded against much more keenly than it has hitherto been. To prevent consultation, however, altogether is just as great an error. Mr. Lineham.

I think it would be a great advantage if engineer employers would connect their firms more directly with the best engineering or technical schools. Something is being done on the Tyne, and Mr. Yarrow has made excellent strides at Poplar; but it passes my comprehension that it should be found necessary to duplicate the labours of the schools by holding examinations at the works themselves. If the right kind of engineers are doing the right kind of teaching, the proverb of the shoemaker and his last is bound to hold good. If employers would discuss matters with the authorities of technical schools, they would find every desire on the part of the latter to meet them in making class work a distinct and direct aid to the apprentice in his practice. In this connection I may mention the recent action of Mr. Drummond regarding the South-Western Railway works and the Battersea Polytechnic, though I fear there is too much tendency to worship the particular form of the connection rather than the connection itself. When in the past the employer has treated the school work with scant courtesy, the apprentice has been only too ready to take his cue accordingly, and the result has very often been a lack of training which is deplorable when viewed in connection with Continental and Transatlantic methods; but if the firms would show their apprentices that a technical training is now considered by them to be a necessity, a very great change of front would be apparent in the ranks.

Scholarships are not a real aid to knowledge among the many. Those of the smaller kind are often obtained by a species of fluke, and our daily experience of that class of scholar is that he is extremely troublesome and disinclined to work, through the false belief that he

Mr. Lineham.

has already achieved his success. Neither is such smaller assistance really required in view of the very moderate fees that hold in the technical schools of England; and the best way to assist a student is to make him feel that there will be a recognition in everyday life of his apparent sacrifice of time and labour in the pursuit of technical knowledge. The higher scholarships, such as those of the late Sir Joseph Whitworth, stand on a different plane, but although Whitworth scholarships have done excellent service in the past, I feel I shall have the agreement of engineers when I say that they do not meet modern engineering requirements, and a thorough revision of them is badly required within the terms of the bequest.

With regard to the discussion to-night, some one told me that he had seen the entrance examination of the Massachusetts Institute of Technology, and he considered it on a very low plane indeed in comparison with English methods. I would also call the attention of the Institution to Mr. Max Wurl's recent paper before the North-East Coast Institution. That paper set out clearly what is being done in Germany, but the part that I want to call attention to is a diagram by Mr. Spence. It is not generally known that Mr. Spence is not only a very old member, but one of the principal founders of the North-East Coast Institution. Mr. Spence contributed a couple of diagrams showing in parallel lines very clearly the education in Germany and the education in England, and the main point of the diagrams was to show that there are always various means of "choking the dog." I believe he indicates about half a dozen ways, both in Germany and in England, of arriving at the same goal. I heartily endorse what Professor Unwin has said in regard to the school workshop. I find the school workshop a great advantage for students, and am certain that very much may be learnt therein. I was especially impressed with Professor Cormack's story about the American who came and looked at English laboratory equipments, and said, "If this is all you are going to do, and if we are at all right in America, God help England." I repeat that. There is one other point I wish to mention as showing how variously we think in England. We have the students here this evening begging on their knees that the lecture work and the laboratory work shall be on a grander scale—shall I call it an Imperial scale?—while, on the other hand, other speakers are saying that this is not at all necessary—that laboratory work should be obtained in the workshop. I am a very old practical engineer myself; I began at an age when other boys were at school. I commenced my training in a drawing office before I was 13, and I have been an engineer ever since. I only left the drawing office when about 30 years of age, and I never found that you could get in the workshops what you can get in the schools. There is an immense amount you cannot possibly touch. The factory is not a place where you can make experiments upon a machine. In order to explain more strongly the position of the factories, I might mention what Sir Benjamin Browne, the great Newcastle employer, and an old chief of mine, said to me when I met him last in Newcastle. He said, "My definition of an engineer is a man who makes machinery or structures for money. Only the man who builds for money successfully is the

engineer who will last—compare George Stephenson and Brunel." That was Sir Benjamin Browne's idea, and that is the idea of the workshops themselves. They are not built for the purpose of teaching students; they are built for the purpose of constructing engineering work; and therefore a student cannot obtain the instruction in the shops that he can get in the colleges; and conversely, he cannot get at the colleges what he gets in the shops. I have nothing further to add to the discussion, except to say that England's technical education has certainly advanced, but other countries had begun their advance before us, and a stern chase is always slow. Dr. Walmsley's paper is a most opportune reminder of our very backward position, and I have no hesitation in saying that it is the most important educational paper that we have seen for a very long time. Mr. Lineham.

(*Communicated*): In further elucidation of my remarks in reference to Mr. W. G. Spence's diagrams, mentioned by me in the discussion, I append Fig. A, showing seven methods of engineering education at present possible in England. The first six are from Mr. Spence's diagrams, and the seventh is my own contribution. I am further encouraged by Dr. Walmsley's remark that "brains do not always go with money," to add to the diagrams a rough statement of the parent's income at present required, neglecting the adventitious aid of scholarships, which can but benefit a few. Referring to each separate scheme :—

I. This being only for the ordinary mechanic, has no special value in the discussion.

II. This also, even though slightly using class work, is merely for the trade student.

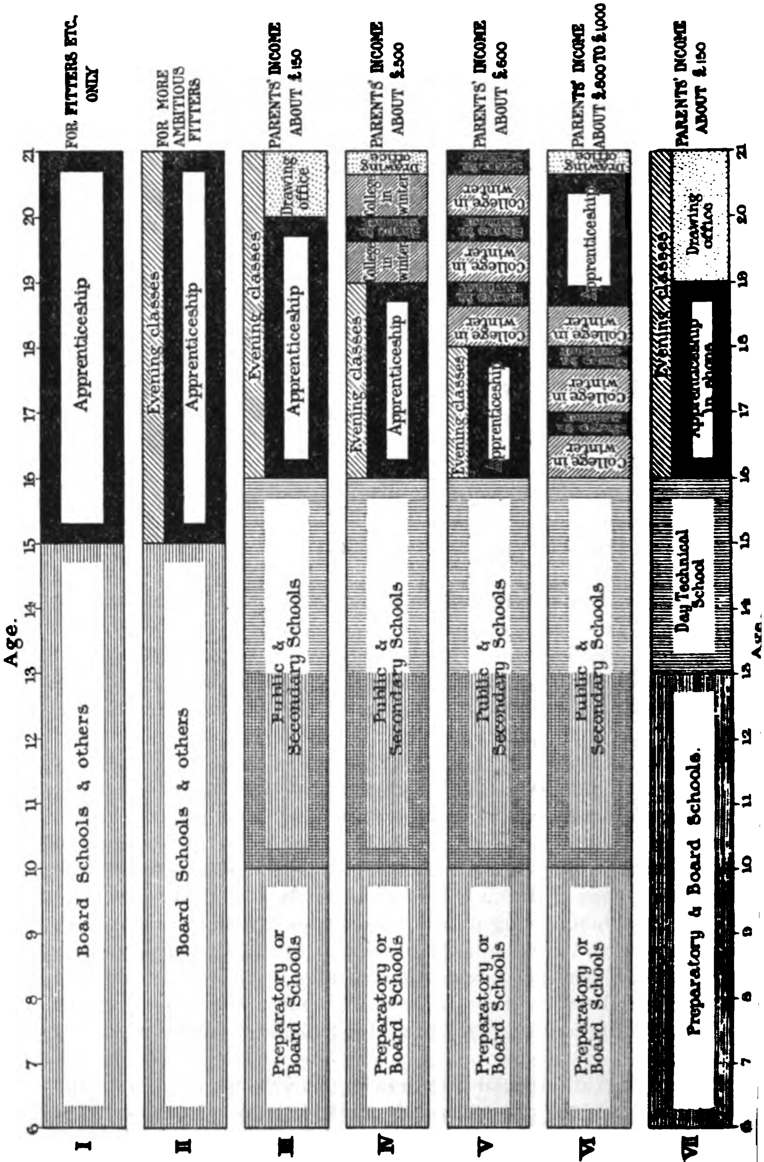
III. As the youth must be kept at school till 16 years of age the parent's income must be quite £150 per annum. The shop apprenticeship being rather long appears to render this scheme suitable for foremen and managers, the drawing office being relinquished again for the shops.

IV. As there is little prospect by this method of earnings before 21, the shop apprenticeship of 16 to 19 merely supplying pocket money, and some premium being most probably required for "workshops in summer," added to which there are the college and class fees, the parent's income would, I think, be rather lowly stated at £500.

V. And this scheme being clearly more expensive, both in class fees and premiums, would entail a £600 income.

VI. The most expensive education of all, requiring considerable payments to employers except in specially enlightened cases, which are few. It will be noticed that the evening classes are deleted in this programme.

VII. I want to call especial attention to this scheme, the last on the list, not because it is the one I have advocated in other places for many years, but because it is an endeavour to reach the golden mean of promoting the welfare of the greatest number of really earnest students. Let us therefore examine it with some care. The parent has only to keep his son at regular day-school up to the age of 16, and comparing with Scheme III. it would certainly seem that £150 income


Age.
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
I
Board Schools & others
Apprenticeship
FOR FITTERS ETC. ONLY
II
Board Schools & others
Evening classes
Apprenticeship
FOR MORE AMBITIOUS FITTERS
III
Preparatory or Board Schools
Public & Secondary Schools
Evening classes
Apprenticeship
Drawing office
PARENTS' INCOME ABOUT £150
IV
Preparatory or Board Schools
Public & Secondary Schools
Evening classes
Apprenticeship
College in winter
Drawing office
PARENTS' INCOME ABOUT £300
V
Preparatory or Board Schools
Public & Secondary Schools
Evening classes
Apprenticeship
College in winter
PARENTS' INCOME ABOUT £600
VI
Preparatory or Board Schools
Public & Secondary Schools
College in winter
Apprenticeship
Drawing office
PARENTS' INCOME ABOUT £800 TO £1,000
VII
Preparatory & Board Schools.
Day Technical School
Evening classes
Drawing office
PARENTS' INCOME ABOUT £150

could suffice. As far back as 1899 I explained the scheme as follows:— Mr. Lineham.

Proposed Course of Education and Training for a Young Engineer up to the Age of 21.

Age.	Occupation.
Up to 13 ...	At a primary school, with preferably some private tuition.
13 to 16 ...	At a technical day-school, studying sciences, pure and applied, and the use of tools.
16 to 19 ...	In the mechanical workshops of a large firm, learning fitting, machining, etc.; evenings to be spent at a technical school, learning the advanced stages of applied engineering science.
19 to 21 ...	In the drawing office of a mechanical, electrical, or civil engineering firm; continuing also his evening study into the highest stages of the subjects.

After 16 the youth would always receive some remuneration for his services, which would relieve his father's burden. I have always advocated that employers should permit evening-class students to begin work at 8.0 a.m. rather than 6.0, and this would be the only concession asked for the student till the age of 19, while the *simultaneous* pursuit of shop experience and theoretical study has advantages that are at once apparent.

The drawing-office experience takes care of itself, and the apprentice who has faithfully pursued Scheme VII. up to the age of 21 may be very well trusted to the world alone as a credit to his backers.

In this scheme there are no sudden breaks, and the school theory can be constantly compared with shop practice to the advantage of both—a process which may be continued till the student be grey-headed. Further, should the pupil be unable to complete his primary education till 14, he will merely enter the drawing office a year later or decrease his workshop time by one year.

Should he again, like his American brother, have saved a little money, at 21 he may, if he pleases, leave his employment and take a college course of one, two, or three years. Two more points and I have done. I regret to say there is a tendency to suppose that evening classes cannot impart that high degree of education which is obtainable in the day-college, and the sooner this idea is dispelled the better. Mr. Buckmaster's story, in the discussion, does much to illustrate and compare. It will be seen that I place the drawing office much earlier than in Mr. Spence's diagrams, and for preference would put it even another year earlier than I have done, reducing the shop time one year; for I have a very strong regard for the experience to be obtained in the office, especially should it be in direct communication with the works.

Professor R. H. Smith: Mr. President and gentlemen, I had noted several points about which it might be useful to speak and which have not been noticed in the discussion, but I am very unwilling to interfere with the members hearing Dr. Walmsley's reply to the discussion, and Professor Smith.

Professor Smith.

I will therefore abstain from any criticism. I will simply thank Dr. Walmsley on my own behalf for the very interesting and valuable information he has given in this paper, and express my hearty agreement with most of the opinions he has stated there. I think certainly he has exhibited too unquestioning an admiration for mere magnitude of establishment and lavishness of expenditure. I do not believe that in England it is at all necessary to imitate that expenditure, and suspect that in America much of the money has been ill spent, and will not be of very permanent value. I agree most emphatically with Dr. Walmsley's statement that good teachers are of infinitely greater importance than all the material and plant that can be bought for no matter how much money.

Professor Maclean.

Professor Magnus Maclean: Dr. Walmsley's paper is very full, and treats of American engineering schools in a very admirable manner. As I recently visited most of the educational and scientific institutions and manufacturing establishments mentioned in the paper, I may be allowed to add some remarks more by way of corroboration of his facts than any criticism of his conclusions and applications. And first, I would emphasise what he says regarding firms who would not consider applications for admission of any candidate who might eventually obtain a position on their scientific staff "unless he can produce a college or university diploma." In this country manufacturers and managers generally seem to look with disfavour upon highly educated youths and college men. At least they give no preference or encouragement to this class over their more ignorant rivals, and consequently the youths themselves finding no advantage in remaining long at school or college, leave early, as the training received seems to carry them no further forward in the actual business and trade of life. On the other hand, the American regards education as the chief national asset. Manufacturers and employers of labour are eager to get technically trained men to direct their work. They show their appreciation by founding and equipping institutes and colleges for the technical training of young men in the various industries; and they further encourage these institutes by giving the college-trained youth a preference over those who are merely shop-trained. "In all departments where high-class work is done," said one employer, "we pay good wages and are always anxious to get technical men. They are broader-minded and have a wider mental grasp than the man who left school at the age of sixteen to learn his trade in a shop. In technical or any other kind of work the young man who has been trained in a technical school very soon overtakes and outstrips the man who has had practical experience only. Their remuneration at first is no greater than that of the others who do similar work, but in almost all cases it increases more rapidly, and there is practically no limit to their promotion, while the man without technical education, unless in exceptional cases, finds his field of operation greatly restricted." Another employer stated his opinion somewhat as follows: The young men who enter the workshop fresh from a technical school are not practical. As a rule they have had just enough shop work to make them think that they are practical, when in

fact they are not. Some of them have exalted ideas of their ability, and if left to themselves will waste material, and therefore are expensive to their employers. But after they have been in the shop a few years, and are drilled in shop methods, they make the best class of mechanics, and can be trusted with the most difficult and important kinds of work. Professor Maclean.

I am pleased to note that Dr. Walmsley puts in italics the fact that in America there is no such practice as having a premium pupil, and that what may fairly be called a living wage is given at the very start.

The point in which their technical colleges rival, and in many instances surpass ours, is their excellent equipment. No expense seems to be spared to make them in this respect as serviceable as possible. Indeed some appeared to me to be over-equipped, the stock of apparatus being so great that it was not likely to be all ever used, and much of it was rather a hindrance to the right manipulation of what was essential and necessary. A great part of the apparatus was either presented, or given at considerable discounts by manufacturing firms. This in itself is a striking evidence of the interest which the manufacturers take in the college work.

Superior engineers are often induced to accept collegiate appointments because of the well-equipped laboratories, and because in the case of the engineering professors they are given opportunity and in every way encouraged to do outside work. It is believed that thus they keep in touch with the various lines of progress in their profession.

The method of teaching general in the United States, except in those of university rank, is that known as "recitation." It consists in prescribing lessons from a text-book, on which the student is examined by means of question and answer, with a good or bad mark in the record book. I have met professors who do not think highly of this system, and who, while they prescribe work for preparation out of a book, simply make each question the basis of part of an explanatory lecture. Oral inter-discussion they hold to be a more effective method than either recitation or lecture. While the training thus given is of a high order, it did not impress me as better, or in some cases even as good as that given in our own institutions.

As Dr. Walmsley appropriately remarks, the present highly developed system of school and college work has only come into operation within very recent times. Therefore in itself it cannot be considered the cause of the national prosperity. The men who made the greatest impression upon American progress, and who at present hold the most influential positions, received their training before the new order of things arrived.

Mr. H. Hirst (*communicated*): I do not pose as an authority on the education question, but give my views entirely as the discussion on Dr. Walmsley's paper strikes me as a manufacturer. Mr. Hirst.

Every manufacturer welcomes a fair percentage of highly educated and scientifically trained men, but he can only do with them in a certain proportion. Personally I should not like to have to manage a "works" where a large number of the staff were as highly learned as, say, the professorial gentleman who spoke last night—under such circumstances

Mr. Hirst. everybody would feel that he was an expert on everything, and a proper division of labour would scarcely be possible.

I distinguish between highly educated people and highly scientifically trained people. Of the latter I should say any "works" would only require about 1 per cent., whilst from the former every member of the staff should, or could, be recruited, according to the nature of the works, in the proportion of 5 to 10 per cent. of all hands employed.

Hitherto my experience has been that "university men" I have met are highly educated, but are devoid of technical training; whilst the gentleman coming from a technical college has frequently proved to be of good technical training, but of very inferior general education.

Whilst thus speaking of what a manufacturer wants, I am, of course, ignoring the requirements of the country generally—the men who study for the love of study, for the love of research, or for the sake of gaining a livelihood professionally. I am only speaking from the point of view of the material from which I would like to form my staff; that is, of the men who eventually earn big salaries in big organisations.

In cross-questioning an applicant for a position I usually consider the following points:—

1. Gentlemanly bearing.
2. Good physical development.
3. Quick comprehension and conception of figures.
4. A retentive memory.
5. An "open mind" and power to grasp problems.
6. A sufficiently complete all-round education to be able to take up successfully any speciality that the applicant might afterwards have to make his own special province.
7. "Secondary accomplishments," such as shorthand, languages, and drawing. (These latter qualifications are not infrequently the reason why one man of apparently the same quality and knowledge as another makes so much faster strides.)

A man who, with pen or pencil, can give his ideas in an engineering business can usually be trusted to be accurate. A man who knows shorthand will be selected quickly as the "handy man." He gets imparted to him daily (probably at high pressure) the train of thoughts of his immediate superior, and his mind will be tuned to think and act more in harmony with that of his principal, who will entrust him with a position of responsibility and confidence in preference to a man equally efficient in all other respects.

A knowledge of languages will always encourage a man to be more cosmopolitan, *i.e.*, less "narrow-minded." It will encourage him to keep himself better informed, not only of what his neighbours are doing, but of what his competitors all the world over are doing—a knowledge which is a most essential point to carry any enterprise to success.

How this effect is to be obtained is not for me to say, but education which will achieve this result will have the backing of every manufacturer in this country.

Technical education in Germany is of comparatively recent date. The men who have made modern Germany and built up its vast indus-

tries have not been men of high scientific training, but men of sound general education, who have made use of highly scientific men with care, moderation, and discretion. Mr. Hirst.

As Mr. Trotter said yesterday, technical education should be more confined to the teaching of principles and theories; the practical education ought to be developed inside actual works.

No college, however fully equipped, will teach a man how to produce an article at a given price. No college will teach him how to design or make an article by submitting it to the simplest number of operations during the process of manufacture. No college can teach a pupil how to handle workmen, and what amount of work to get out of them with the greatest efficiency for the employer. No pupil can learn organisation of stores or the control and checking of men. Until a pupil knows what to get out of machines and men he will not be worth any salary to his employer, and I therefore think that the time which, according to some of the speakers yesterday, he is to employ playing about with machinery and apparatus in the museums and workshops of the college, would be better employed by spending it "on the field of battle" in works.

I mention this latter for two reasons—first, to dispel the hopes of those educationalists who think that by advancing education to an hitherto unknown degree they can turn out the finished article; secondly, there is an old saying, "You can take a horse to the water, but you cannot make him drink."

Many students with proclivities for technical training develop an absolute incapacity for absorbing more than a moderate amount of scientific knowledge, but very frequently they show great ability in a practical direction, and by leading a college life too long they miss opportunities which they would have had had they spent a good portion of this time in a works.

Before concluding, I wish to take this opportunity of commenting on the frequently mentioned statement that American manufacturers make more use of scientifically trained men than English manufacturers. I hold the view that large works in this country employ the same percentage of scientifically trained men as do the large works in America.

It is undeniable that America possesses a larger number of big works, and therefore employs a greater number of scientific men. The reasons for this, to my mind, are the subject of the present fiscal controversy, to which I need not refer in detail here.

The fact (frequently mentioned yesterday) that inventions by scientific men of this country prove very often unremunerative here, but yield big profits in countries like America and Germany, is one more instance of the probable effects of Protection on Education.

Mr. E. Kilburn Scott (*communicated*): The part of Dr. Mullineux Walmsley's paper which specially appeals to me is where he refers to the practice in the States and Canada of requiring teachers of engineering subjects to engage in outside professional work, and also to the giving of special courses of lectures by engineers connected in practice with the subject of the course. Mr. Kilburn Scott.

Mr. Kilburn Scott.

I believe that this is the key to the whole situation, and the advantages are so obvious that it is difficult to understand why it is not acted on more extensively in this country. In my own lecturing experience I have found advanced students intensely interested in anything connected with the details of every-day practice, and the methods by which difficulties are met. Their interest is particularly keen in anything touching ever so remotely the commercial side, and whether it is right or wrong to impart such information in a technological institute or college, there can be no question as to the demand for it. As a matter of fact, of the many students who take up engineering, very few indeed have any chance of getting into the designing department, and especially into the estimating or technical-commercial side, for the exigencies of business are against allowing continual changes of staff in such departments. This being so, it appears to me that they are fit subjects to teach advanced students. How else, for example, is a young man to train for the position of "sales-engineer"; as it is, the pick of such positions in this country are held by Americans who appear to have received a special training for the work.

Specialised practical information can only of course be given by those who are actually engaged in practical work, and it seems to me that the Principal or even the Chief of a department in a teaching institution has quite enough to do without undertaking outside professional work. An excellent way, and one which the author himself has adopted, is to have outside lecturers connected more or less permanently with the institution. Such lecturers give regular courses according to a syllabus, and not merely short courses of three or six lectures; these latter are all very well in a way, but do not go far enough.

Of course it is not everybody who cares to take up such lecturing in addition to his other work, but a sufficiently high scale of remuneration would go a long way towards attracting the right men, and it would be better to spend funds in this direction than in elaboration of buildings or plant. One excellent feature of such a system is that the outside lecturer is enabled to take note of the smarter students, and he may possibly be of assistance in getting them suitable situations. In this connection it may be mentioned that the late Professor Short, when he was in the States, built up a concern which threatened the great Westinghouse Company itself, and this was mainly with the assistance of men who had been his own students.

An outside lecturer is also able to give information as to *how not to do things*. For example, in machine design the text-books describe only the successful designs, or at any rate do not comment to any extent on the failures, yet it is from such failures that one may learn most. Those who have never actually designed practical machines and gone through the ruck of it, cannot possibly discriminate between the good and only moderately good, nor can they appreciate the various little points touching the commercial side of design, which is after all the main thing.

I am often asked by students as to what they are to do under

certain circumstances. For example, one is tired to death of the drudgery of central station shift work, another has had a misunderstanding with his employer, another has received an offer of a position abroad, etc. In these cases it is a pleasure to me to know that I was enabled to give the advice which turned out well, and which I was simply enabled to give by being so *closely identified* with practical work. Mr. Kilburn Scott.

Regarding Polytechnics and evening classes, although it appears to be the fashion in certain quarters to sneer, yet there is no doubt whatever that they are doing a most excellent work, in that they are training the non-commissioned officers of engineering. Just as the non-com's. are the backbone of the Army, so the head draughtsman, the works manager, the foreman, the draughtsmen, leading hand erectors and mechanics, and the handy men of the small shops are the backbone of engineering practice. Polytechnics do the greatest good to the greatest number, and those connected with them can afford to smile at the superior persons whose whole idea of educational perfection is residence at a fossilised university.

Regarding the question of expense, I look on education, particularly technical education, as a kind of national insurance, just as are the Army and the Navy. The fighting of the future is going to be a question of brains rather than physique, and other things being equal, that nation which spends most on education is bound to come out on top. Care must be taken, however, to see that the money really goes into education, and not into mere bricks and mortar and plant.

Mr. T. A. Locke (*communicated*): The reading of Dr. Walmsley's paper has been a source of great pleasure, and one feels convinced that he has laid bare many startling and deplorable facts in connection with our engineering educational systems at home, whilst making it perfectly evident that much has to be quickly done in order that we may regain and maintain our industrial supremacy. We are justly proud of our technical institutions and they are not very much inferior to those of our cousins across the water, who love to do things on an immense scale, perhaps rather than on an economical scale. But there is room for improvement at home. One of the main points to be deduced from the paper is that it is absolutely necessary that there should be co-operation between the technical institutions and the manufacturers. It must be fairly obvious to any one who has seriously thought about the matter that much of the best talent produced by our engineering colleges is made of little or no use because of the peculiar conservatism of manufacturing firms. More than once has the writer of these remarks mentioned the great advantage to be gained from allowing technical students to spend their summer vacation in the shops of some firm, and in many cases those students who could have this opportunity would be very willing to conform to the somewhat mistaken and useless practice of paying a premium if only they could make such good use of their time. As Dr. Walmsley points out, the firms also would have the advantage of being able to bespeak suitable men for their future needs. The sifting of men, not through the diplomas they can Mr. Locke.

Mr. Locke. show simply, but through actual acquaintance with their practical capabilities, would go far to the making of better progress in the engineering industries, and would give such an impetus to those who have brains and are willing to train them properly that England would go forward with leaps and bounds to a position of much greater eminence industrially and commercially than she has hitherto attained. But so long as the impression is prevalent among students, that after their three or four years of labour in some technical institution they will have to take their chances of making a living, without even a probation, which chances are far poorer than those of the untrained man, so long will there be a dearth of men having the best possible equipment as engineers or as important men in whatever industry. In this country, in the vast majority of cases, brains without private means are reckoned as of no account. Firms do not seem to seek true ability as much as they ought. They are easily satisfied with very moderate ability or none at all so long as the premiums are paid. Surely the gain to the firms concerned would be far greater if pupils or apprentices were taught to work hard and intelligently, and were given some inducement in the form of a living salary, even if no more. It ought to be well known by now that the present method of training men in the shops alone is of no avail.

In central station work advertisements are often put out for various positions, a mechanical training in the applicants being required, even more sometimes than an electrical training. This is perfectly right in a great many cases, but when one knows that some of the men who are successful in their applications have never done a tithe of the work they should have done, which reduces their shop experience to something which is nearly useless, one is apt to feel somewhat dubious as to the value of the profession. If merely to "say" is more valuable than to "do," then woe betide any industry! There are many cases in the knowledge of the writer of men who are capable and thorough in their work, but who are kept out of the running for good positions because of the lack of a recognised passage through the shops, and yet their life's experience has been such as to make them able to tackle almost any machine work that could be given them to do in competition with those who have been through the shops. It certainly seems from the rapid progress made in American engineering that we must adopt some of their methods. The Manhattan station superintendent shows great discretion. Is it too much to ask that manufacturers should inquire into the benefits they would derive from making a commercial use of the talent of engineering graduates and abolish the obnoxious premium system? Let us have capability, not influence, whether it be found in well-to-do or not-well-to-do persons. With respect to the material equipment of technical schools and colleges, it may be a rather wild suggestion (the outcome of the Purdue University case), but it may be practicable if thought out, that manufacturers make loans of plant or apparatus which is quite up-to-date, say, for two or three years and change the material as new inventions or improvements come out, thus sending men out into the world who have experimented with the things they are likely to use, instead of with

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more or less antiquated machinery. By making such frequent changes the plant would not suffer much in wear, and manufacturers would not lose. Besides, it might not come to the turn of any firm to supply plant again for a considerable time. If they had many valuable improvements in a short time, it would doubtless pay them to make more frequent changes. Of course we cannot expect firms to develop into college philanthropists at present, at any rate, so the suggestion must wait awhile.

Speaking as one who has not only passed through one of the best technical institutions in England, but is in a responsible position and also a lecturer in electrical engineering, one is, of course, cognisant of many matters concerned with our profession looked at from different points of view. There seems to be a need for more careful selection of pupils in our training institutions, in order that the best work may be done by both pupils and instructors. When unsuitable men are practically forced into the work by parents or guardians who are given to expect great things from it, there is considerable impediment put in the way of those who intend to do good work, because of the necessity for instruction to be given to pupils as classes. Probably a month or two at the end of the first year at college in some engineering works where solid results would be expected would quickly convince the undesirables of the anomaly of their present course in life.

Mr. Robson

Mr. E. S. A. Robson (*communicated*): In perusing Dr. Walmsley's interesting paper the lesson of British slowness in acquiring fresh educational ideas is brought into sharp contrast with the up-to-date alertness of the Americans harnessing all their intellectual forces to the development of engineering.

During a tour which I made in the States last autumn for the purpose of visiting the various educational institutions I was struck by the splendid system of secondary education, giving the youth either a modern or manual training, thus fitting him for entering the well-equipped colleges of engineering. The keenness of the youths in obtaining this higher education is evidenced by their desire to save up money while working in the shops to pay for fees and maintenance while studying. I noticed at the Armour Institute several engineering students working their way by performing service in the library or in he office. One student was even acting as elevator-man for a short eriod each day. In the students' dining-hall at Chicago University he waiters were students, and likewise the cashier—all fine fellows, vell dressed, and I have no doubt they considered they were giving ull value in return for the free tuition. It is not uncommon to find in ther institutes apprentices who have served their time, and who wish prepare themselves for high positions by attending the day schools f technology. Such grit and determination is well deserving of iccess.

As regards the equipment of the engineering schools, the huge size certain machines is rather striking when compared with the ractice of schools of engineering in this country or even in Germany. ersonally I should prefer to see an electrical engineering laboratory ted with a large number of moderate sized motors and dynamos of

Mr. Robson. various patterns, such as one sees at the Darmstadt or Carlsruhe Technical High Schools in Germany, rather than the larger ones at the Massachusetts Institute of Technology.

The teaching in the technical schools and colleges is very complete on its practical side, but it seems lacking in depth on the theoretical side. I noticed that American teachers are not up to date in their mathematical teaching, and reform as to the treatment of geometry or the early introduction of the calculus seems to be needed. Further, their undue reliance upon textbooks and disregard for "heuristic" method generally seems rather a weakness, while the small amount of chemistry that is done by students would surprise even an English schoolboy. It is only fair to say that the new laboratories for Physical Chemistry at the Boston Institute are extremely good, while the laboratories at Johns Hopkins and Chicago Universities are equipped with every facility for research. As Dr. Walmsley has noted, the amount of shop work done by the students is such as will enable them to take a place in any works without having to go through any probationary period as our own students are accustomed.

Speaking of schools of technology only, the Massachusetts Institute is superior to anything we have in England, the nearest approach to it being the new Manchester Institute of Technology. Many of the American schools of engineering are practically monotechnic institutes in contradistinction to the polytechnics here, and consequently better equipment and staffing is observed in any one department.

The disparity between the numbers of engineering students in America and England is vividly shown by Dr. Walmsley's figures. I should like to give some figures comparing American and German Technological Institutes.

The American figures are taken from the report of the Bureau of Education 1900–01, while the German statistics are borrowed from an article on German Technical High Schools by Dr. F. C. Rose, British consul at Stuttgart.

STATISTICS OF DAY STUDENTS ATTENDING COURSES IN INSTITUTES OF TECHNOLOGY.

American Schools of Technology:

	Staff.	Students.
1. Massachusetts Institute of Technology	181	1,277
2. Stevens Institute, Hoboken, N.Y. ...	23	241
3. Worcester Polytechnic, Mass.	32	270
4. Armour Institute, Chicago, Ill. ...	47	566
5. Purdue University, Ind.	71	1,049
6. Iowa State College	32	1,064
7. Case School of Mines, Cleveland, Ohio	23	267
8. Rose Polytechnic, Terra Haute, Ind.	21	133
9. Rensselaer Polytechnic Inst., Troy, N.Y.	19	225
Total ...	449	5,092

German Technological Institutes: Mr. Robson.

	Staff.	Students.
1. Aix	66	665
2. Berlin	402	4,194
3. Brunswick	52	472
4. Darmstadt	108	1,700
5. Dresden	87	1,082
6. Hanover	86	1,523
7. Carlsruhe	126	1,685
8. Munich	115	2,804
9. Stuttgart	95	861
Total	1,137	14,986

Now compare with the above statistics the staff and students in advanced day courses of scientific instruction in the Technological Institutes of Great Britain.

Taking a similar number (9) comprising the following institutes:

1. Central Technical College, London.
2. Finsbury Technical College, London.
3. South Western Polytechnic, London.
4. Merchant Venturers College, Bristol.
5. Municipal Technical School, Birmingham.
6. University College, Sheffield (Technical Dept.).
7. Manchester Institute of Technology.
8. Heriot-Watt College, Edinburgh.
9. Glasgow and West of Scotland Technical College.

I have omitted other institutions deserving of mention in order ɔ equalise the area which the institutions serve.) These nine instiutions have a total staff of 245, and the total number of students is nly 2,081.

It is evident that there is plenty of leeway to make up in our nglish Technical Institutes, and the ability to do this will mainly epend on (1) the attitude of the employers towards technically trained en intending to follow the profession of engineering; (2) a large crease in the number of scholarships from secondary schools to places higher education; (3) an increased earnestness on the part of the ritish youth.

The British employer is waking up in the matter, and the results of inquiry concerning "British, German and American apprenticeship stems" which I made recently is most encouraging. In further wing public attention to this matter Dr. Walmsley has done a great vice and should receive the hearty support of all who are interested the welfare of the country.

Mr. O. I. Davis, Student (*communicated*): Dr. Walmsley's paper s come at a most opportune moment, and its contents serve to phasise the fact that the time is ripe for some concerted action to be en in order that manufacturers and those in charge of technical ools and colleges may work hand in hand, as seems to be the case in Mr. Davis.

Mr. Davis. the United States, in order to secure that finished product which is the ultimate end of good technical and workshop training.

There is a somewhat broad line of demarcation between the Technical College and the Technical School in this country. Few specimens of the former seem to exist. In them, as a general rule, the fees are high and a certain amount of previous technical, or at any rate preparation for technical work is required. Hence it follows that the courses of instruction are more complete, and a fuller instruction in any one branch is capable of being given than is the case in a technical school where time has to be taken in preparing the students. In the latter, the fees are low, evening classes are the rule rather than the exception, and the courses are more specialised than in the college.

I consider that the lavish equipment of the American colleges and schools is to a great extent responsible for the statement made on page 408 of the paper to the effect that too much attention is paid to the "kilowatt" side of electrical engineering and not enough to the "milliwatt," as the student is naturally attracted by the appearance of heavy electrical machinery, with which he acquaints himself to the detriment of his purely scientific training. Two much stress cannot be laid on the importance of the possession of good and accurate measuring and standardising appliances, as also on the provision of means for obtaining accuracy in delicate testing work, as on these depend the confidence of the student in himself. Much of the extensive equipment of the Transatlantic schools and colleges may probably be traced to the large number of post-graduate students in attendance. For research work, such equipment, as for instance a means for obtaining high voltages, is necessary, but in most cases it has scarcely sufficient claim to be made permanent.

As Dr. Walmsley remarks that he has found men trained at the Central Technical College holding their own against American trained men even in the latter's own country, perhaps a few comparisons between the curricula of this and the American colleges may not be amiss. I have collated the electrical engineering course of the Central Technical College as being that of most interest to members of the Institution, in accordance with Dr. Walmsley's tables, and present it below:—

Subjects	Hours.	Per Cent.
1. English History	Nil	Nil
2. Modern Languages	Nil	Nil
3. Mathematics, Pure and Applied	510	18·7
4. Mechanics, Physics and Chemistry, Lectures and Exercises	210	7·7
5. Mechanics, Physics and Chemistry, Laboratory	450	16·5
6. Mechanical Technology, Lectures	120	4·4
7. ,, ,, Laboratory	30	1·1
8. Freehand Drawing and Descriptive Geometry	30	1·1
9. Machine Drawing and Design, including Graphics	240	8·8

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Subjects.	Hours.		Per Cent.
10. Structural Design	Nil		Nil
11. Electro-Technics, Lecture and Design	385	...	14·1
12. „ Laboratory ...	600	...	22
13. Metallurgy	Nil		Nil
14. Law and Economics	20	...	·7
15. Miscellaneous	9	...	·3
16. Shop Work	120	...	4·4
17. Thesis Work	Nil		Nil
Total Time — Hours	2,724	...	99·8
Total Time — Weeks	...	90	
Total Time — Years	...	3	

The chief differences to be noted are the preponderance of Mathematics and Electro-Technics, especially the laboratory work in the latter. The Mathematics course at the Central Technical College is extremely good, especially that part of it which, dealing with the mathematical theory of electricity, is delivered to the third-year students. The Electro-Technics course, both in lectures and in practical work is most complete, and full attention is paid to the more delicate tests. The percentage hours of work under the heading Machine, Drawing and Design, including Graphics, is rather smaller than seems to be the case in most American institutions, but this is partly due to the fact that part of the work is included under the heading sixth on the list. Reports have to be made on every experiment, investigation, or work performed in the electrical laboratories by the third-year students.

An important point in technical education is the training of students to train themselves. In this the necessity of a well-arranged first year's course of instruction is apparent. The work in the first year is often elementary, and thus the course seems rather discouraging to the more advanced student, especially if the time-table is so arranged as to render the work monotonous. Perhaps a sound mathematical training does more to enable the student to think for himself than anything else. A mathematical proof, though it is not often remembered, presents its results very forcibly, and after all the result is more useful than the proof. I consider the system mentioned in the paper of indexing extremely useful; as is also the presence of a really good library of standard technical works.

Mr. Williams.

Mr. W. J. Williams, Student (*communicated*): A perusal of Dr. Walmsley's interesting paper cannot fail to impress upon one the elaborate equipment of technical institutions in America, and one is inevitably led to ask the question: Is such equipment with its consequent expense necessary, or is it even desirable? Speaking as a student, my answer is emphatically negative. There are many reasons for this, and the following are perhaps the chief. First, it has been agreed by most people that college training should teach principles, and I think that for this purpose small machines will answer just as well as some of the larger ones installed in the American colleges. Secondly,

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a student takes much more interest in testing a small machine that is doing some useful work in the college, than a large one whose power is probably being wasted. Thirdly, it must not be forgotten that the design of modern machinery changes rapidly, and it therefore follows that, if the colleges are to keep pace with modern developments, they must be continually adding to and replacing their machines. If large machines are to be used, the expenses in this direction would far exceed the present incomes of many of our technical institutions. Furthermore, most engineers are agreed that college training must be supplemented by experience in works, and I see no reason why acquaintance with large machines should not be obtained there.

There is a point with regard to practice in the college shops which I should like to emphasise, and that is the duration of one period in the shops. In my opinion this should always be as long as possible. From my own experience as a student I know that very often in a period lasting over three hours quite 80 per cent. of the work is done in the last hour.

In conclusion I may say that it is my opinion that we have in England some (very little, perhaps) technical and secondary education quite as good, if not superior to that in America or Germany. What is needed is not to copy German or Transatlantic methods, but first, to sift out the wheat from the chaff in our own country, and then, finally, vast extension and co-ordination.

Dr. Walmsley.

Dr. WALMSLEY, in reply, said: Mr. President and gentlemen, the President has privately asked me to make my remarks short and to communicate the bulk of my reply to the *Journal* later on, therefore I wish very briefly to refer to a few points only, and chiefly to questions on which the inquirers may like to have an answer immediately. I may first of all say that I submit very strongly that General Webber's report justifies my remarks about secondary education: I may amplify that later on. Mr. Symons asked whether students' engineering societies existed in America. Yes, they exist very numerously indeed, and they publish their Proceedings. I have several handsomely bound books at home which I brought back with me, produced by the engineering societies of America. I may mention one little incident which I obtained secondhand. A few years ago the Westinghouse Company took over to Pittsburgh some Englishmen to prepare them for the Trafford Park Works. There were, I was told, sixty or seventy Englishmen, and, like most Englishmen, when they got together they formed a club: that club still exists in Pittsburgh although the Englishmen have come back. A day or two ago I received the *Electric Club Journal of Pittsburgh*, No. 1 of vol. 1, so that it is still developing.

With regard to Professor Unwin's remark that America is larger than England, and the population is about double, which is perfectly true, and that therefore there is a great demand for engineers, I would like to remind the Institution that England is not the British Empire, and that India, South Africa, Australia, and all over the British Empire we have a territory that far exceeds that of the United States, and which we should engineer.

Some little confusion I think has perhaps crept into the discus-

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sion owing to the fact that the different speakers did not recognise that in England there are technical colleges and technical colleges, and that remarks which are perfectly justified about one set of colleges are certainly not justified about another. I quite agree with Professor Unwin that at the Central Technical College he does get students as well prepared as any students that go into the technical colleges in America, but that is not the case all over the country, and I am very sorry that it is not the case. Mr. Trotter asked whether there were any enthusiastic teachers in America. I can say yes, but I shall only mention one because he has left us since I saw him, namely, Professor Thurston, of Cornell University. A more enthusiastic teacher you could not find anywhere. I met many others, but as they are still with us I shall not mention their names.

Professor Cormack incidentally mentioned something about engineering courses in secondary schools. Of these I entirely disapprove. Secondary schools should keep to their work and leave the engineering course to the engineering colleges. I have given examples in the paper of what to avoid in that direction, examples drawn from America and its manual training schools, which are simply secondary schools with engineering courses.

Dr. Glazebrook asked, "Is it necessary to spend sums comparable with those spent by America?" If you search my paper through you will find I have not said it is necessary. I have put the facts before you; I have said that expenditure is necessary, but I have not attempted to name any figure. I may say personally I think it is not necessary to spend on the same scale; but that we do want certainly to spend on a much larger scale than we have hitherto attempted here. As for every parent paying the full value, as mentioned by Mr. Harrison, of the engineering education of his sons, I would ask Mr. Harrison to remember that brains do not always go with money, and that if we are to get the brains of the country into the engineering profession we must rise to the same position in regard to education which has been reached in America, and recognise that it is for the good of the community that education of this kind shall be provided at the cost of the community. In those western universities on the prairies Mr. Lineham said he was astonished at the high fees. I ask him to look at the fees in the Illinois University, which are represented in my table by a cypher. That university was started entirely by State Funds with very few private benefactions (it is given in the table on p. 390); and so convinced are the inhabitants of many of the States in the Union, and the Union generally, of the value of education, and so much do they believe in it, that they are quite willing to find the funds so that the education given to the rising generation shall be the best procurable.

I should like to remind the Institution of what I have said somewhere in the paper, that you cannot draw general conclusions from isolated cases in America. You have there all kinds of education, good, bad, and indifferent. Education is unfettered. The Bureau of Education is simply a statistic collecting authority exercising no control whatever. As regards education, it would seem that every man does that which is right in his own eyes, but he does it generally with know-

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ledge, and he gathers his information from all parts of the world—I had distinct evidence as to that. They keep in their libraries careful records of all that is going on in the educational world, and the professors are constantly consulting these records, and then a man does, unfettered by central control, that which he thinks right. There are many other points that I should like to refer to, but availing myself of your suggestion, sir, I shall make my further reply in writing and communicate it to the Journal.

(*Communicated*): In replying more fully to the twenty speakers and writers who have taken part in the discussion on my paper, an attempt will be made to leave no material point unnoticed without recapitulation of what is already contained in the paper, though this will be difficult. Since speakers and writers have ranged over many topics in common, it will be more convenient if, instead of taking their remarks *seriatim* as recorded, I refer generally to the questions with which they have dealt, and only occasionally mention the individuals who are responsible for the opinions considered.

Many of the speakers have insisted on the necessity for closer touch being maintained in this country between the manufacturers on the one hand and the technical schools on the other, and this is one of the points which I endeavoured to emphasise strongly in the paper. Mr. Trotter asks whether the manufacturers or the schools are to blame, and suggests that it may be that the schools are not turning out the right material. In the paper I have emphatically said that the employers hold the key of the position, and have given reasons for this assertion. I am glad to see that some of my critics quite agree with me upon this point. I regret, however, that manufacturers were not more numerously represented in the discussion. The remarks of Mr. Hirst, since communicated, are extremely valuable as showing the necessity for manufacturers giving much more attention to what the schools are doing than, I believe, is generally the case. To take one of his groups of criticisms first: no up-to-date technical school in this country at the present time is under much delusion as to what it can or cannot do. Such a school knows perfectly well that it cannot "teach a man how to produce an article at a given price," that it cannot, except approximately, "teach him how to make an article" in the most labour-saving way; that it "cannot teach students how to handle workmen," and that it can only give the principles of "the organisation of stores," and cannot teach the "control and checking of men"; and, moreover, the schools are fully alive to these and other similar points. That there is, however, still a wide field for their work and that there is still a great deal to be done which cannot be done upon Mr. Hirst's "'field of battle' in works" is also very clearly known, and what the schools want is the co-operation of the employers to show them exactly the best points to take up so that the time in the schools may be most advantageously employed with a view to future work. If manufacturers as a body would spare some little time to giving the schools in the neighbourhood of their works the benefit of their personal advice and assistance, apart from any material support, a distinct step would be gained. Some already do this with excellent results, but the numbers are too few.

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Mr. Hirst's estimate that the works would only require one per cent. of "scientifically trained men" and from five to ten per cent. of "highly educated people," is a liberal one; but if he will kindly obtain statistics from the leading manufacturers in the United Kingdom, I am under the impression that he will find that his estimates of the needs of the manufacturers in these directions are far from being reached in practice. In fact had it been the custom throughout the country to employ this percentage of trained assistants, including amongst the "highly educated" those who have been highly educated on proper lines in technical schools or colleges, the present output in the United Kingdom would have been miserably inadequate to supply the demand. I cannot, therefore, in view of the actual numbers of the men who are turned out annually and fulfil Mr. Hirst's description, accept his opinion that the large works in this country employ the same percentage as in America, but I am quite open to conviction if Mr. Hirst will furnish data upon the point averaged over a large number of engineering and other works.

The fact reported by Mr. Lineham that a large employer of labour has asserted that all a young engineer wants is a "Molesworth," speaks volumes as to the attitude of many employers towards the schools, an attitude which I venture to assert is a mistaken one, and probably due in most cases to the fact that the employers do not understand what the best schools are doing.

In this connection I would call attention to a remark made in my spoken reply that there are "technical colleges and technical colleges," and I believe that technical education in this country has suffered in the opinion of many manufacturers from the fact that there are some technical colleges which are not run upon correct lines. Mr. Buckmaster, an expert educational critic, in his remarks supports me in this opinion when he says that "the technical college in this country hardly yet realises what it is intended to do, and what it can do." He referred, of course, not to the best colleges where the conditions are very clearly apprehended, but to those technical colleges which, keeping to antiquated and out-of-date academical methods, have not thoroughly studied the problem which they have to face. That such colleges may have an adverse influence for some time to come is emphasised by an incident which has occurred recently in the appointment of a Principal of a provincial technical college. In this instance, although the chief work of the college was to be engineering work, and there were one or two good candidates who were thoroughly acquainted with the necessities of the locality and the best modern methods of technical teaching, these candidates were passed over for a man who had no technical training whatever, but who happened to have personal friends on the Governing Body and some influence with county families. Appointments like this make one despair of the future of technical education in England, and quite account for the remarks of Mr. Hirst and others, if it be clearly understood that these remarks are only of limited application.

There is one other remark of Mr. Hirst's which might be dealt with before leaving this part of the subject, namely, the points which he

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considers when interviewing an applicant for a position. Some of these are purely personal and have no reference to the college or other scholastic training of the applicant, but the more important of them are such as every graduate from a properly conducted technical college should be able to present to his prospective employer. I refer to "quick comprehension and conception of figures"; "an open mind and power to grasp problems," and such an education as will enable the applicant "to take up successfully any speciality." It is for the latter that the training of a technical college should especially qualify its students by giving them a sound foundation of technical knowledge and principles upon which to build. Professor Armstrong's advice "that we should adopt the plan of training students from the research point of view—from the point of view of developing their thinking power and their originality—more than we have been in the habit of doing," is only what good technical schools worth their salt persistently keep in view, though they may not make use of the much-abused word "research."

Is it too much to hope that in the future employers may be willing to give the real technically trained man some preference, and that in examining the qualifications presented they will make some inquiry with respect to the kind of work done in the institution in which these qualifications have been obtained. If this course be adopted the up-to-date institutions need not fear the test of their products in actual life, and will cease to suffer from the present unconscious confusion with the other class of schools referred to. The evils of the premium system referred to in the paper and by several speakers, and the yielding to influence instead of ability in making promotions should also be seriously considered by the employers.

Turning now to the schools and their work, it is certainly difficult, as Professor Unwin observes, to compare the conditions of entrance to the schools with those obtaining in this country, and as a matter of fact the only proper means of making a fair comparison is to have practical experience extending over one, two, or three years of both sets of conditions. As this is impossible, we must proceed by inference, and although I fully admit the fairness of Professor Armstrong's criticism that the fact that secondary school work is done in the professional schools of America tends to show that the preparation is not so thorough as the paper asserts, still I adhere to the opinion that the preparation is better in the States than in England. The secondary school work, in my opinion, is rather due to the fact, also noted by Professor Armstrong, that, in many cases, the colleges are too academic and have not yet shaken themselves quite free of the old traditional methods of teaching. Other speakers have referred to the same point.

The difficulty of arriving at an accurate and reliable opinion upon such an important point as the entrance conditions emphasises the value of such a procedure as is foreshadowed in General Webber's remarks, and of the action which is now being taken to obtain a standard of general culture for the leaving conditions of the secondary schools. If such a standard can be obtained it will be a great step in

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advance, and it does not at all necessarily mean that the curricula of the schools are to be moulded in a cast-iron frame. It is to be hoped that this important question will not be allowed to rest.

With regard to college workshops, the general concensus of opinion to be gathered from the debate is that the view taken in the paper is the correct one, namely, that the college workshop cannot replace the commercial workshop, but that it has a distinct function of its own which is of great value in the training of engineers. The trend of the best English practice in this respect therefore seems to be approved, and it appears to be agreed that the educational workshop should not attempt to turn out skilled workmen, but that to a great extent it should be confined to familiarising the students with the chief constructive processes by actual practice with the various kinds of tools and machines, and with the possibilities and limitations of the machines when dealing with different materials and also for the purpose of experimenting. It is partly because of the last-named function that I cannot agree with Professor Cormack's observation, that where a "sandwich" system is in vogue and the students are periodically drafted into commercial workshops there is no necessity for college workshops. I would like to point out to Professor Cormack and one or two other speakers, that in the commercial workshop engaged in its work of production it is quite impossible to allow or to encourage the experimenting with machines which is of such great use from an educational point of view. Mr. Lineham clearly recognises this when he says that you "cannot get in the workshops what you can get in the schools," though his remark, of course, has a much wider application.

Mr. Kilburn Scott's remarks upon the necessity of having teachers who are engaged in outside work as permanent members of the staff, and not simply as peripatetic lecturers, are worthy of serious consideration, as are also his remarks, and those of one or two other speakers, that the evening classes for engineering are doing excellent work. I cannot, however, agree with Mr. Lineham's model scheme of education as set forth in his written remarks, and which would condemn the engineering student after the age of sixteen to obtain all his technical education in evening classes. Although evening classes do excellent and advanced work, and work which cannot be too highly praised for those who, for one reason or another, cannot take advantage of day classes, it must be recognised that the training so obtained has to be paid for at a very serious physical cost to the student. That earnest students should be found in large numbers who, after a heavy day's work, will give the time and face the mental effort necessary to advance their knowledge of the scientific side of their industry is a fact deserving of all admiration, but the physical exhaustion which they must face should not be lightly ignored. Attempts should be made to smooth the path for the admission of large numbers of these earnest students with their undeniable "grit" to the greater advantages of the day courses. All honour to them for their assiduity and hard work against heavy odds, to which should not be added cheap sneers and depreciation of their work.

Turning next to Mr. Harrison's comments, I think it will not be

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possible for him to find in the paper any expression to the effect that before we have made up our present leeway we must spend ten millions upon equipment and ten millions upon endowment. Nowhere does the paper say that it is necessary to rival in mere magnitude the equipment of the American colleges. It is quite true that the paper overlooks, or rather does not refer to, unendowed institutions, and the reason is that the writer believes that such institutions cannot meet the necessities of the case. The difficulty lies in the necessarily high fees which must be charged, a difficulty upon which I have already commented in my spoken remarks, when I reminded Mr. Harrison "that brains do not always go with money." Perhaps I should have put it the other way round and said that money does not always go with brains, and I repeat the opinion that "if we are to get the brains of the country into the engineering profession we must rise to the same position in regard to education which has been reached in America, and recognise that it is for the good of the community that education of this kind shall be provided at the cost of the community." Mr. Harrison thinks that although the parent should pay for the education, you cannot ask him to pay for the "undoubtedly much wanted" equipment, but to my mind the difference is only one of degree. If it be reasonable to ask the parent to pay the whole cost of tuition and maintenance, why should he not also pay a reasonable percentage on the cost of the equipment and its depreciation. Mr. Harrison is much exercised in his mind that public money should be spent upon "wasters," but I would go further and say that it is undesirable that any money, whether public or private, should be spent upon a waster, or that he should in any way get just as much paid towards his professional education as the really able and industrious student. It is exactly in this point that the endowed institution has an enormous advantage over the unendowed one, for the former, when properly conducted, has no hesitation whatever in firing out the "wasters" at the end of the first year, or, at the best, giving them the option of repeating their first year's work over again with a chance of amendment. I should be much surprised to learn that in the unendowed institution with its high fees this practice obtains to anything like the same extent.

There is another direction in which Mr. Harrison appears not to be posted in the practice of good technical schools, when he says that it is "the worst possible training to give the student at the start elaborate apparatus." No well-organised technical school does this. The starting apparatus is of the simplest character, and it is only when fundamental principles have been mastered that the elaborate apparatus is called into use. But here again I differ from Mr. Harrison, in that I hold that the apparatus for the higher work should be in the technical school and not in the factory, if only for the reason mentioned above, that in the factory opportunities for experiment cannot be found in the same way as in the school, and that if the student is to trust to the factory plant for his educational experimental training he will come very badly off. It is quite another thing when, later on, he experiments with this then familiar plant for the purposes of the factory and not with an educational object.

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As Professor Unwin appears to consider that the figures I have given on page 401 of the paper regarding English students cannot possibly represent the number of students undergoing technical education in this country, it would be well for me to explain that these figures are taken from statistics gathered by the Association of Technical Institutions for the year 1900–1. The data were collected officially from nearly all the important schools of the country, the only notable omission being the Royal College of Science, London, and they include the City and Guilds Technical Colleges, as well as the polytechnics and provincial technical institutes. That both Professor Unwin and Professor Fleming regard the figures as not representing the present position fairly is encouraging evidence of the fact that we have not been standing still for the last three years, and that we are steadily moving forward, although the writer would like to see the pace accelerated. There is no doubt, I think, about the accuracy of the figures for the period named. They refer, of course, to day students only, and it is gratifying to note that Professor Fleming now credits London with 1,200 engineering day students, or more than one-half of the engineering day students of the whole country three years ago.

Referring to Professor Armstrong's remark, that although "there may be a good deal of provision made for research there is not much evidence of research work being done," I wonder whether he has seen the lists of original work which are annually published by most of the large universities of America. To take only two instances, I have before me such lists for the Cornell University for the year 1902–1903 and for the University of Pennsylvania for the year 1901–1902. In one case the titles only of the various papers and publications which have issued from the University as part of its work during the year extend to 34 pages, and in the other case to 31 pages. Such instances could easily be multiplied. This is not the place to criticise the actual details of the work set forth, but at least it may be confidently asserted that there is a fair amount of evidence of research and of original work having been attempted.

I was surprised at Professor Armstrong's statement that he had found that employers in the States were abandoning their scientific assistants, and I can only say that although this was a point upon which I made diligent inquiries, I found no evidence of such retrogression.

More than one speaker seems to have gathered the impression that the paper is too pessimistic. The writer admits that it is not optimistic, but he submits that it is not really pessimistic, although it attempts to show that we have fallen behind. On the other hand it does endeavour to point out how matters may be mended, and as the methods are not absolutely hopeless, the term pessimistic appears somewhat severe.

More than one speaker asks, should we copy the United States methods? Nowhere in the paper is this recommended, but there is all the difference in the world between slavish copying and absolutely ignoring the lessons which are to be learnt from the experiences of others. No one in his senses would seek to transplant all the methods which obtain in the United States and Canada to the very different

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social conditions which hold in England, and if the paper be read carefully there will be found in it much in the direction of teaching what not to do as well as what to do.

Many other points were raised by various speakers to which I would like to refer, but I feel that this reply is probably already too long. I must therefore assure those speakers and writers that consideration of space only, and not any want of courtesy or appreciation, causes me to pass over their remarks in silence.

In conclusion, I desire to thank sincerely my auditors and critics for the kindly way in which they received my paper, and to hope that it, and more especially the discussion to which it has given rise, may have some little influence for good on the development of higher engineering education in England.

The PRESIDENT announced that the scrutineers reported the following candidates to have been duly elected :—

Members.

James H. Cawthra.	Andrew B. Maclean.

Associate Members.

Percival T. Blissett.	Joseph A. Panton.
Robert W. Fletcher.	Edgar S. Rayner.
Wilfrid N. Kernot, B.C.E.	John Skerritt.
Thomas Holme.	Percy H. Stewart.
Louis Jean Le Clair.	John Williams.

Charles W. Zoephel, jun.

Associates.

Henry H. Arthur.	Stanley C. Manchester.
Charles W. Bloomfield.	George R. Pepper.
Charles E. Clayton.	Frederick H. Rudd.
Maurice E. J. Gheury.	Sydney J. W. Scott.
Stanley Harris.	Oliver S. Spokes.
Joseph H. Heywood.	Horace A. Stewart, B.Sc.
Ernest A. Lambert.	George Sykes.
Arthur Loving.	Urmson Willan.

Students.

Walter E. C. Adye.	William Dancer.
Hugh A. Arbuthnot.	Evan Davies.
James Auckland.	Lionel H. Dermer.
Leslie W. Ballard.	Joseph M. d'Horschel.
James R. Barr.	John Dobson.
Alfred M. Beale.	Leonard C. Downman.
Thomas W. Chalmers.	Athol C. Dufort.
Henry B. Cresswell.	Hugh N. Dutton.
Harold G. Y. Crowder.	Arathoon G. Edgar.
Harold W. Curling.	Walter N. Elley.

Herbert C. Flower.
George L. Gifford.
William A. Gosse.
Frederick Charles Grund.
Hubert D. Harris.
Frank De Betham Hart.
Sidney B. Haslam.
Henry S. Hayden.
Reginald B. Holmes.
Leonard L. Howard.
Kau Htu.
Herbert R. Hudson.
Duncan C. M. Hume.
Horace Irle.
Paul H. H. Jantzen.
Lionel Lamb.
E. James Martin.
John G. Murray.
Robert B. Murray.
Francis A. G. Noel.
George S. Payne.
John S. Percy.
Arthur C. Pesterre.
Herbert S. Phillips.
Harold W. Pink.
Edward A. Powell.
George V. Pullen.
William A. Ritchie.
John Robinson.
William A. Scotter.
Albert Slaughter.
Alfred K. T. Smith.
Albert Stanton.
Frederick W. Strickland.
Marshall H. Tate.
John William Taylor.
Everard F. Thornton.
Ashton L. Trickett.
Alfred E. Turpin.
Frederic R. Unwin.
Alfred Vipan.
Harold E. Webb.
Samuel W. Webb.
Herbert A. Wootton.
George E. Worthington.
Arthur Zoller.

The Four Hundred and Fourth Ordinary General Meeting of the Institution was held at the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, March 10, 1904—Mr. ROBERT KAYE GRAY, President, in the chair.

The minutes of the Ordinary General Meeting held on February 25th were, by permission of the meeting, taken as read, and signed by the President.

The names of new candidates for election at the Institution were taken as read, and it was ordered that they should be suspended in the Library.

The following transfers were announced as having been approved by the Council :—

From the class of Associate Members to that of Members—

Edward Herbert Cozens-Hardy. | Harold Hastings.

From the class of Associates to that of Members—

Arthur Cecil Heap.

From the class of Associates to that of Associate Members—

Herbert Jackson. | William Edward Sotheby.
J. H. Woolliscroft.

From the class of Students to that of Associate Members—

Charles Bounett.

Messrs. A. C. Heap and J. S. Fairfax were appointed scrutineers of the ballot for the election of new members.

Donations to the *Library* were announced as having been received since the last meeting from J. W. Meares; to the *Building Fund* from J. R. Bedford, H. G. Beeton, A. P. Pyne, W. W. Strode, A. Wright; to the *Benevolent Fund* from A. H. Bate, J. H. Woolliscroft; to all of whom the thanks of the meeting were duly accorded.

The following Paper was read in abstract :—

THE RATED SPEED OF ELECTRIC MOTORS AS AFFECTING THE TYPE TO BE EMPLOYED.

By H. M. HOBART, Member.

The continuous-current motor has done such excellent service and has so many useful properties, that one is inclined to regard the induction motor as an unnecessary innovation. Indeed, while on the one hand, one now clearly sees the way for still further increasing the range

of usefulness of the continuous-current motor and understands the lines on which its manufacture may be greatly cheapened, without detriment to its good qualities, it is, on the other hand, apparent that the induction motor, even with a commutator, has limitations as regards efficient speed regulation, power-factor, and in other respects, which must inevitably limit its sphere of usefulness.

In one respect, however, the continuous-current motor is very defective; it is essentially a slow-speed machine. When designed for moderately high speeds, serious concessions in the interests of commutation have to be made; it becomes not only expensive, but faulty in many respects. At still higher speeds it must, pending further developments, be condemned as a complete failure.

On the other hand, all the properties of the induction motor improve with increasing rated speed. These facts are significant, and since the differences in the characteristics of the two classes of motors, far from being minor matters, are most marked, and since, furthermore, it is characteristic of electrical engineering that transformations not only of voltage, periodicity and phase, but also from continuous-current to alternating-current and *vice-versâ* may be efficiently made, and generally without entailing prohibitive first cost, it would appear to be a reasonable suggestion that it would in many cases pay to employ continuous-current for low-speed and induction motors for high-speed work, even in the same plant.

Whether the practicability of this proposition is admitted or not, it is nevertheless desirable that the nature of the changes in the characteristics of these two types of motors with increased rated speed, should be clearly understood.

Now it is most difficult to make consistent assumptions as the basis for a number of comparative designs, but I have taken for a set of continuous-current designs, for a 150-H.P.* shunt motor, five speeds ranging from 68 r.p.m. to 1,224 r.p.m., and, without figuring out the details with any elaboration, have nevertheless endeavoured to proceed on fairly reasonable lines. I have followed this same policy with two groups of induction motors, the first group being for 21-cycle motors ranging from 36 poles and 68 r.p.m. to 4 poles and 612 r.p.m., and the second group being for 63-cycle motors and ranging from 12 poles and 612 r.p.m. to 6 poles and 1,224 r.p.m. Although I should have preferred to concentrate attention upon the influence of the speed, and not to enter upon the question of the influence of the periodicity, the extreme range of speeds which I wished to cover made this impracticable. Thirty-six poles is already abnormal enough for a 150-H.P. induction motor, and yet this leads to a group of three motors, the last of which, at 630 r.p.m., has but four poles, thus requiring stepping up to a higher periodicity for a higher speed design. The lower the frequency, the more does the sphere of usefulness of the induction motor extend towards the lower speeds.

* I have made this investigation for motors of 150-H.P. rated output. The conclusions would quantitatively be modified for other outputs: thus for motors of 75 H.P. the continuous-current motor's sphere of advantage would extend to higher speeds.

The general design of these eleven motors and some of their lead constants are set forth in Figs. 1 to 11, and 1A to 11A. In Fig. 12 shown curves roughly indicative of the relative factory costs of th eleven designs for the three groups. These costs have been deri from the product of diameter D, of rotor in centimetres and le L, over armature winding in centimetres, *i.e.*, from $D \times L$ for continuous-current machines. The windings of induction motors be less definite as to over-all length, L has been taken equal to the g core length λ_g, plus seven-tenths of the air-gap pitch τ, *i.e.*, L = $+ 0{\cdot}7\,\tau$ for the induction motors. $D \times L$ has been found to be fa proportional to the total factory cost for continuous-current dyna electric machines, for a given voltage and for so-called "barrel"-wo armatures. The same expression has also been found fairly proporti to the total factory cost for induction motors.

The total factory cost may thus be set equal to $K_c \times D \times L$ continuous-current motors, and to $K_i \times D \times L$ for induction mo where K_c and K_i are constants for any one firm. The ratio of K K_i which we may denote by R $\left(R = \frac{K_c}{K_i}\right)$ has been found to v greatly with different manufacturers. From a study of the data ki supplied to me for the purpose by four manufacturers, it is belie that 1·5 is a fair value to take for R for the purposes for which required in this paper. Thus for motors having equal rotor dimensi the continuous-current motor will be taken as costing 50 per c more than the induction motor. This, however, would not be ratio of cost for the same *output*, because different diameters lengths would be taken in the two cases. As a rough value for total factory cost of continuous-current motors 1·00 shilling per D may be taken (although this varies considerably with different ma facturers), D and L being expressed in centimetres. Hence shilling per $D \times L$ will be the corresponding total factory cost induction motors. This would rise to 0·75 shilling per $D \times L$ motors with wound rotors, and would fall to 0·60 shilling per D for motor, with squirrel-cage rotors.* At low speeds the diam would be much greater in the case of induction motors. At h speeds, and especially at low periodicities, the reverse would the case. This is shown in Fig. 13. In the upper part of Fig are given the full-load efficiencies for the continuous-current the induction motors. Whereas the former are lower for the hig speeds, the efficiencies of the induction motors rise fairly rapi starting from a very low value for the lowest speeds. In lower part of Fig. 14 are given corresponding curves of half-l efficiencies.

From Figs. 15 and 16, it may be seen how the power-fac improves with the speed, and how the no-load current at the same t decreases.

* This paper does not concern itself with *absolute* costs. The co parisons are purely relative. Nevertheless, it serves to fix ideas to em some unit of value, and the equivalent chosen has been shown to approximately in an article published in No. 40 of the *E.T.Z.* for 190

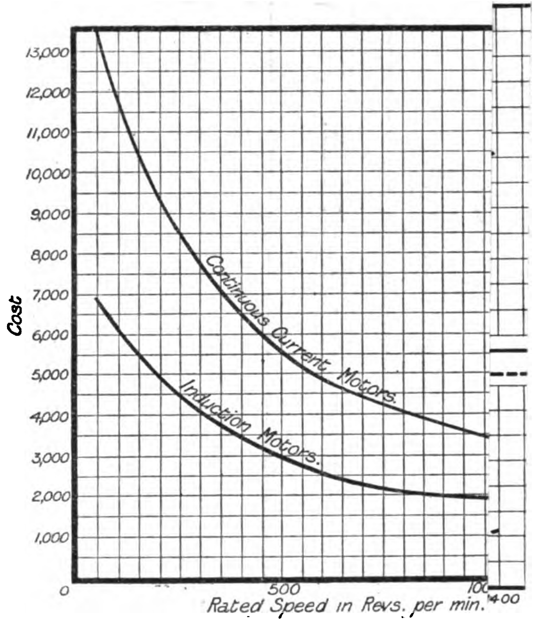

FIG 12.

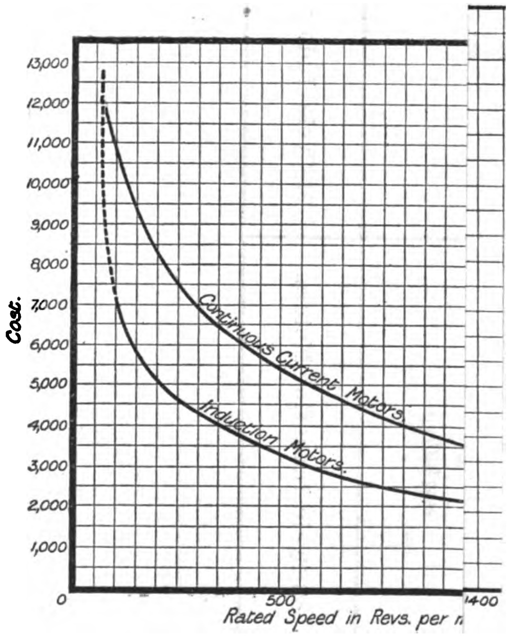

FIG. 12A.

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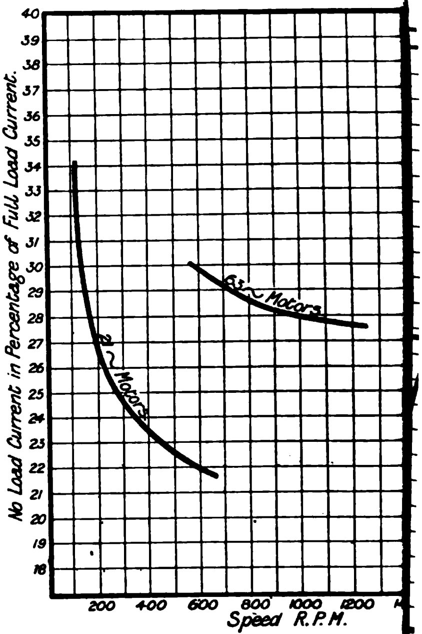

FIG. 16.

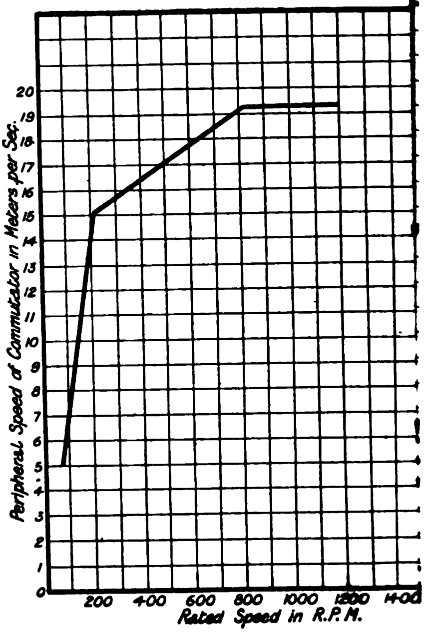

FIG. 18.

Fig. 17 shows the increase in reactance voltage at full load, for increasing rated speed. As is evident, the results are very unfavourable for the higher speeds, whereas they are decidedly favourable for the lower speeds.

The peripheral speed of the commutator in meters per second is shown in Fig. 18. Where special, and as yet, not thoroughly proven methods of commutation are not resorted to, these high commutator speeds must be employed for high-speed designs of continuous-current dynamos.

It is thus evident that with increasing speed, while all the properties of the induction motor improve markedly, the reverse is the case for the continuous-current motor, and one would be inclined to believe that this points out the best field for these respective types, and that the influence of the speed should be taken into consideration when other circumstances permit.

For the 150 H.P. designs on which the comparison is based, giving fair regard to cost and performance, the continuous current holds, in my opinion, the advantage up to some 600 r.p.m., as compared with 63-cycle motors, and up to some 400 r.p.m. as compared with 21-cycle motors.

In the neighbourhood of these limits, the advantages of the one or the other type are fairly equivalent.

Although as has already been stated, the demonstration of the influence upon the results (very favourable for induction motors and exceedingly unfavourable for continuous-current motors), of increase in the rated speed, does not, owing to the preponderating extent of this influence, require the exercise of any great care in the preparation of the designs compared, it is nevertheless of interest to set these forth in some detail. A more careful study of each of the individual designs might easily lead to a considerable percentage improvement in the results for a given cost, or in the cost of the results obtained.

Where continuous-current and induction motors come up for comparison, it is natural that one should seek for some common ground as a basis for the designs. It has seemed to me that the most significant common attribute for this purpose, is the ratio $\frac{\lambda}{\tau}$, in which λ equals the length of laminations between end flanges (λ_g = gross core length and λ_n = nett core length) and τ = polar pitch at the air-gap, *i.e.*, the circumference at the air-gap divided by the number of poles. As already described, the cost of the induction motors has been taken proportional to $D \times (\lambda_g + 0{\cdot}7\, \tau)$, and the cost of the continuous-current motors to $D \times L$ where L = length over end connections. In general for continuous-current motors, L is also approximately equal to $\lambda_g + 0{\cdot}7\, \tau$, although in the case of well-defined windings having the end connections lying in extensions of the armature core's external cylindrical surface, it is more instructive to use the expression $D \times L$ as the basis for cost estimates and comparisons.

$\frac{\lambda}{\tau}$ is again useful in obtaining the value of C in Behrend's formula

150 Horse-Power Continuous-Current Motors.

Revolutions per Minute	68	204	612	817	1,224
SPECIFICATION.	A.	B.	C.	D.	E.
Number of Poles	8	8	6	6	4
Kilowatts Input as Motor	126·7	126·0	127·3	126·8	127·8
Full Load Voltage	350	350	350	350	350
„ „ Amperes	361	360	363	362	364
External Diameter of Armature (D)	146·0	146·0	100·0	90·0	60·0
Gross Length Armature Laminations – (λg)	48·0	15·0	12·0	12·5	14·0
Polar Pitch – (τ)	57·5	57·5	52·5	47·0	47·2
Length of Armature over Winding $L = \lambda g + 0·7\tau$	88·2	55·2	48·8	45·4	47·0
D × L. (This is proportional to the Total Factory Cost)	12,900	8,060	4,880	4,080	2,820
Number of Ventilating Ducts	8	1	1	1	1
Width of each Duct	1·0	1·0	1·0	1·0	1·0
Effective Length of Laminations in Armature Core (λn)	36·0	12·6	10·0	10·3	11·6
Internal Diameter of Armature Laminations	100·0	100·0	56·0	48·0	23·0
Diameter of Commutator	140·0	140·0	56·0	45·0	30·0
Length of Commutator	12·0	12·0	24·0	30·0	45·0
Width of Segment at Surface (including Insulation)	0·393	0·393	0·368	0·368	0·368
Total Number of Segments	1,120	1,120	480	384	256
„ „ „ Slots	224	224	120	96	64
Number of Segments per Slot	5	5	4	4	4
Turns per Segment	1	1	1	1	1
Width of Slot (as Stamped)	1·18	1·18	1·04	1·04	1·24
Depth of Slot	3·0	3·0	3·0	3·0	3·0
Radial Depth of Air-Gap	·5	·5	·5	·5	·5
„ Length of Magnet Core	25·0	25·0	25·0	25·0	25·0
Equivalent Diameter of Magnet Cores	36·0	21·0	18·5	18·0	18·0
Cross Section of Magnet Cores (Sq. Cms.)	1,020	347	270	255	255
Shape of Cross Section of Magnet Cores	Circular	Circular	Elliptical	Elliptical	Elliptical
Pole Face Dimensions	48 × 40	15 × 40	12 × 34	12·5 × 30·5	14 × 29·8
Ratio of Pole Arc to Pole Pitch	·692	·692	·640	·640	·620
External Diameter of Magnet Yoke (D_1)	225·0	212·2	165·0	154·6	124·0
Width of Magnet Yoke	48	35	30	30	30·5
Radial Thickness of Yoke	12	5·6	5·0	4·8	4·5
Height of Armature Conductors	1·05	1·05	1·05	1·05	1·05
Width „ „	·13	·13	·14	·14	·18
Current Density in Armature Conductors (in Amperes per Sq. Cm.)	330	328	411	410	482
Thickness of Armature Slot Insulations (Copper to Irons)	·125	·125	·125	·125	·125
Space Factor in Armature Slot	·386	·386	·378	·378	·405
Average Voltage per Commutator Segment	2·5	2·5	4·38	5·46	5·46
Amperes per Sq. Cm. of Brush Contact	3·75	3·75	3·75	3·75	3·75
Total Armature Interference (Ampere Turns per Pole)	6,320	6,300	4,850	3,860	5,820
Types of Winding	8 Circ. Single	8 Circ. Single	6 Circ. Single	6 Circ. Single	4 Circ. Single
Paths through Armature Winding from + to – Brushes	8	8	6	6	4
Amperes per Pole	45·1	45·0	60·5	60·3	91
Length of Arc of Brush Contact	2·0	2·0	2·0	2·0	2·0
Frequency of Commutation in Cycles per Second	126	378	450	482	482
Mean Length of Armature Turn	240	180	150	138	138
Embedded Length per Turn	72	25	20	20	23
Free Length per Turn	168	155	130	98	115
Reactance Voltage with Full Load Amperes	1·3	1·76	2·44	2·4	4·12

[illegible]	20·0	30·0	10·0	18·6	[illegible]
[illegible]	8,800	8,000	8,450	8,800	9,050
Cycles per Second for Reversal of Magnetisation in Armature Iron	4·55	13·0	30·0	40·9	10·9
Total Armature Flux at Full Load Rated Voltage (Megalines) ...	12·9	4·35	3·47	3·26	3·26
Factor for Magnetic Leakage ...	1·2	1·2	1·2	1·2	1·2
Flux in Magnet Cores (Megalines) ...	15·5	5·22	4·16	3·91	3·91
Density in Magnet Core ...	15,200	15,200	15,400	15,300	15,300
Density in Magnet Yoke (Lines per Sq. Cm.) ...	13,400	13,400	14,000	13,700	14,200
Pole Face Density ...	6,700	7,250	8,500	8,580	7,800
Field Ampere Turns at Full Load ...	6,000	6,000	6,000	6,000	6,000
Material of Magnet Yoke ...	Cast Steel	Cast Steel	Cast Steel	Cast Steel	Cast Steel
" " " Cores ...	"	"	"	"	"
" " Armature Sheets ...	Steel	Steel	Steel	Steel	Steel
Peripheral Speed of Armature Meters per Second ...	5·2	15·6	32	38·5	38·5
" " Commutator " " ...	5·0	15·1	18·0	19·3	19·3
Centrifugal Force at Armature Surface in Kilogrammes per Kilo ...	3·8	34	208	335	500
" at Commutator Surface ...	3·62	32·6	116	167·5	250

Losses and Efficiencies at 60° C.

Core Loss ...	3,150	3,200	4,200	3,800	2,300
Armature Copper Loss ...	8,000	6,000	3,580	2,660	3,150
Commutator C^2R Loss at Brushes ...	580	580	580	580	580
" Brush Friction Loss ...	320	940	1,120	1,160	1,160
Loss in Shunt Winding ...	1,600	1,070	830	820	620
Friction Loss at Bearings and Air Friction ...	1,000	2,200	5,000	5,800	8,000
Total Constant Losses ...	6,040	7,300	11,090	11,550	12,060
" Variable " ...	8,580	6,580	4,160	3,240	3,730
Total of all Losses ...	14,650	13,990	15,310	14,820	15,810
Commercial Efficiency Full Load ...	88·4	89	88	88·3	87·6
" " ¾ " ...	88·3	88·2	86·2	86·3	85·5
" " ½ " ...	87	86	82·1	81·9	81·0
" " ¼ " ...	80·5	78·1	71	70·2	69·4
Watts per Sq. Dcm. of Peripherial Radiating Surface of Armature ...	27·5	36·2	49·5	48·5	61
Watts for Commutator Surface ...	17	28·6	40	41	41
Watts per Sq. Dcm. of External Cylindrical Radiating Surface of Field ...	6	0·05	6·2	6·26	7·05

Weights and Costs in Kilogrammes and Shillings.

Weight of Armature Laminations ...	2,275	800	415	340	195
" " " Copper ...	328	246	94	69	50
" " Commutator Copper ...	235	235	190	190	190
" " Field " ...	406	245	175	169	100
" " Pole Faces ...	243	77	40	36	26
" " Magnet Core ...	1,760	555	323	306	204
" " Yoke ...	3,050	1,040	600	530	410
Total Weight of Effective Material ...	8,297	3,198	1,837	1,660	1,184
Cost of Copper (at 2·0 Shillings per kilogram ...	1,940	1,450	920	840	700
Cost of Laminations (at 0·6 Shilling per kilogram)* ...	1,500	525	250	225	130
Cost of Cast Steel (at 0·4 Shilling per kilogram ...	1,920	635	365	330	245
Cost of Net Effective Material ...	5,360	2,610	1,535	1,395	1,075
" " " per H.P. ...	35·7	17·4	10·2	9·3	7·2
Total Factory Cost in Shillings per H.P. Output (from D × L rule) ...	86	53·7	32·3	27·2	19·3
Percentage which Cost of Net Effective Material bears to Total Cost ...	41·5	32·5	31	34·5	38·4

* This price is for completed discs, and includes labour and waste material.

TABLE II.

(All dimensions are in Centimetres.)

150 Horse-Power Induction Motors.

	21 Cycles per Second.			63 Cycles per Second.		
Rated Horse-power	150	150	150	150	150	150
Number of Poles	36	12	4	12	8	6
Synchronous Speed in Revolutions per Minute	70	210	630	630	940	1,260
Voltage	350	350	350	350	350	350
External Diameter of Stator Punchings	318·2	132·4	84·1	114·8	85·8	70·8
Internal " " " "	292·4	107·4	51·1	90·4	60·4	45·4
External " " Rotor " (D)	292·0	107·0	50·7	90·0	60·0	45·0
Radial Depth of Air-Gap (Δ)	0·18	0·18	0·18	0·18	0·18	0·18
Internal Diameter of Rotor Punchings	272·0	87·0	30·0	70·0	40·0	25·0
Circumference at Air-Gap	920·0	338·0	160·0	283·0	190·0	143·0
Polar Pitch at Air-Gap τ	25·6	28·2	40·0	23·7	23·7	23·7
Gross Length between Flanges (λ_g)	16·7	48·0	48·0	20·0	30·0	43·0
Number of Ventilating Ducts	0	3	3	1	2	3
Width of each Ventilating Duct	—	10	10	10	10	10
Net Length Laminations between Flanges λ_n	150	400	400	171	252	360
$\frac{\lambda_n}{\tau}$	0·585	1·42	1·00	0·72	1·07	1·52
Type of Slots Employed	⅜ Closed	⅜ Closed	⅛ Closed	⅜ Closed	⅜ Closed	⅜ Closed
C in Behrend's Formula	10·8	10·2	10·5	13	11·9	11·2
$\sigma = C \frac{\Delta}{\tau}$	0·075	0·0645	0·0465	0·098	0·090	0·085
Maximum Power-factor	0·870	0·886	0·915	0·840	0·848	0·855
Watts Output at Full Load	112,000	112,000	112,000	112,000	112,000	112,000
Full Load Efficiency	86 %	89 %	90·5 %	90·5 %	91·3 %	91·8 %
Watts Input at Full Load	130,000	125,800	123,800	124,000	122,800	122,000
Volt-Amperes Input at Full Load	149,000	141,500	135,500	147,500	144,800	142,500
" " " per Phase	49,700	49,700	49,700	49,170	48,270	47,500
Connection of Stator Windings	Δ	Δ	Δ	Δ	Δ	Δ
Volts between Terminals	350	350	350	350	350	350
Volts per Phase	350	350	350	350	350	350
Full Load Amperes per Stator Winding	142	135	129	140	138	136
Energy Component of Full Load Amperes per Stator Winding	123	120	118	117	117	116
Full Load Line Amperes	246	234	223	243	239	235
Dimensions of Bare Conductor in Stator	·5 × 1·27	·45 × 1·05	·35 × 1·3	·4 × 1·12	·4 × 1·12	·4 × 1·12
" Insulated Conductor in Stator	·55 × 1·32	·50 × 1·1	·40 × 1·35	·45 × 1·17	·45 × 1·17	·45 × 1·17
Solid or Stranded	Stranded	Stranded	Stranded	Stranded	Stranded	Stranded
Cross Section of one Stator Conductor	0·54	0·47	0·386	0·445	0·445	0·445
Current Density at Full Load	262	377	334	314	312	306
Depth of Stator Slot	3·4	3·0	3·5	3·2	3·2	3·2
Width " "	1·43	1·38	1·55	1·75	1·75	1·75
Number of Conductors per Slot	4	6	6	6	6	6
Arrangement of Conductors in Stator Slot	2 × 2	3 × 2	3 × 2	3 × 2	3 × 2	3 × 2
Number of Stator Slots	432	144	72	108	72	54
Total Number of Stator Turns	[illegible]	432	216	324	216	162
Number of Stator Turns per Phase	[illegible]	144	72	108	72	54

[illegible]	[illegible]	970	960	284	447	[illegible]
[illegible]	1·15	1·15	1·15	1·15	1·15	1·15
[illegible] Section	354	910	1,100	320	515	685
Gap Density—Average	3,810	3,540	4,850	3,650	3,480	3,470
Maximum Gap Density	6,460	6,000	8,200	6,200	5,900	5,850
Ampere Turns for Gap	920	850	1,170	890	845	840
Total Ampere Turns	1,080	1,000	1,420	1,050	980	960
Ampere Turns per Pole per Phase	540	500	710	525	490	480
Maximum Current at No Load	67·5	50·0	39·5	58·5	54·5	53·5
R.M.S. Current at No Load	48·0	35·4	28·0	41·5	38·5	37·8
" " in Percentage of Full Load Current	34·0 %	26·2 %	21·7 %	29·6	27·9	27·8
Total Radial Depth of Stator Punchings	12·9	12·5	16·5	12·7	12·7	12·7
" " " above Slot	9·9	9·5	13·5	9·5	9·5	9·5
Magnetic Cross Section of Stator Core (*i.e.* above Slot)	2 × 142	2 × 380	2 × 520	2 × 162	2 × 239	2 × 342
Stator Core Density	4,750	4,250	5,150	3,660	3,750	3,490
Width of Tooth at Narrowest Point	7·1	5·1	7·1	9	9	9
Cross Section per Pole at Narrowest Point	128	305	510	138	203	356
Maximum Density at any Stator Tooth at Narrowest Point	17,900	17,900	17,900	14,700	15,000	14,000
$\frac{DC}{100}$ for Stator	1·00	0·89	1·08	2·31	2·36	2·20
Watts Stator Core Loss per kilogram	1·5	1·3	1·6	3·5	3·6	3·4
Net Weight Stator Punchings (kilograms)	1,400	1,500	1,100	520	570	640
" " Rotor " "	1,000	1,000	500	330	320	320
Core Loss in Stator Iron	2,100	2,000	1,800	1,800	2,100	2,300
" " Rotor Iron	420	400	360	360	420	460
Total Core Loss	2,520	2,400	2,160	2,160	2,520	2,760
Embedded Length of one Stator Turn	30	80	80	34	50	72
Free " " "	73	80	110	67	67	67
Mean " " "	103	160	190	101	117	139
Total Length of each Stator Winding (*i.e.* Winding One-Phase)	29,600	19,200	13,700	10,900	8,400	7,506
Resistance per Phase at 60° C. – Ohms	0·109	0·082	0·071	0·0577	0·0382	0·034
Total Stator C^2R Loss	6,500	4,500	3,500	3,500	2,250	1,930
" Rotor " "	8,100	5,300	4,100	4,000	3,350	2,900
" Core Loss (Stator and Rotor)	2,520	2,400	2,160	2,160	2,520	2,760
Allowance for Friction Loss	1,200	1,600	2,000	2,000	2,200	2,400
Total of Losses	18,320	13,800	11,760	11,660	10,320	9,990
Output in Watts	112,000	112,000	112,000	112,000	112,000	112,000
Input "	130,320	125,800	123,760	123,660	122,320	121,990
Full Load Efficiency (in Per Cent.)	86·0 %	89·0 %	90·5 %	90·5 %	91·3%	91·8%
Weight of Stator Copper (kilograms)	415	240	140	127	102	89
" Rotor " "	285	170	100	88	60	52
Total Weight of Copper Conductors	700	410	240	215	162	141
" " Laminations	2,400	2,500	1,600	850	890	960
Cost of Copper at 2·0 Shillings per K.G.	1,400	820	480	430	324	282
" Laminations at 0·6 Shilling per K.G.*	1,440	1,500	960	510	530	575
" Net Effective Material (in Shillings)	2,840	2,320	1,440	940	854	857
Cost per H.P. for Net Effective Material (in Shillings)	18·9	15·5	9·6	6·2	5·7	5·7
Diameter of Rotor (D)	292	107	50·7	90	60	45
$L = \lambda_g + 0·7\,\tau$	34·7	67·7	76	36·6	46·6	59·6
Total Factory Cost of Motor (0·67 × D L)	6,700	4,850	2,610	2,200	1,870	1,820
Cost of Effective Material in Per Cent. of Total Cost	42 %	48 %	55 %	43 %	46 %	47 %

* This price is for completed discs, and includes labour and waste material.

for the leakage factor σ which is

$$\sigma = C \frac{\Delta}{\tau}$$

Δ being the radial depth of the air-gap.

The writer obtains the values for C from curves showing it as a function of the ratio $\frac{\lambda}{\tau}$, and finds that this leads to results rather more accurate than are otherwise obtainable from Behrend's formula, and far more conveniently arrived at than by means of the more complex formulæ sometimes employed for the estimation of σ.*

In the case of the induction motors the radial depth of the air-gap has been taken at 0·18 cms. for all cases. This is not in accordance with practice. A lesser gap with the corresponding electro-magnetic advantages would be employed by most designers for the higher speed designs. But to avoid entering into the discussion of the most suitable respective values, I have adhered throughout to the value of 0·18 cms. and the induction motors come out so greatly superior to the continuous-current motors at high speeds, that they are well able to stand this handicap.

For a moderate range of speeds, for the same output, say a range of 1 to 4, I should have taken the same number of poles and the same diameter for all my continuous-current designs, as I find this to be a practicable and correct designing principle for this class of machinery. Here, however, with a speed range of 1 to 18, the lower speed designs are given more poles and larger diameter, and *vice versa* for the higher speed designs. The range of diameters is, however, far less than is customary with most designers, and this is a point of interest, since, although I do not claim to have devoted to each design more than enough attention to ensure a sound demonstration of the main proposition, it nevertheless appears that, in this respect, the designs are about right for the required conditions.

Further details of these eleven designs are given in Tables I. and II. (pp. 476, 477).

It is interesting to derive the costs by another and independent method which consists in determining the cost of the effective material on the one hand and of the non-effective material independently on the other. The latter component can be derived if a sufficient number of machines of the same diameter, but of variable length, are plotted with the cost of the non-effective material as ordinates, and the effective length l as abscissæ. By these means a curve can be obtained which, if produced, intersects the axis of ordinates at a point giving the cost of non-effective material for zero effective length of armature.

This has been investigated by the author as described in *E. T. Z.* No. 40, 1903, and it has been found that the cost of the non-effective material for zero nett length of armature core equals approximately

* Where desirable, it is practicable to determine σ with still greater accuracy by a modification of the above method which I have published in a contribution to the discussion of Dr. Behn Eschenburg's recent Institution paper entitled, "On the Magnetic Dispersion in Induction Motors, and its Influence on the Design of these Machines," *Journal I.E.E.*, vol. 33, 1904, p. 239.

$\frac{D_1^2}{10}$ shillings, if D_1 denotes the external diameter of the yoke in cm. Such a curve also shows the increase in the cost of the non-effective material in dependency upon the nett length of the armature core, and taking into account the influence of the diameter, one could roughly set this increase as equal to $0{\cdot}18\ D_1 \lambda_n$.

The estimation of the costs by this method is carried out in Table III. for the continuous-current motors.

Table III.

Estimation of Total Works Cost of 150 H.P. Cont.-Curr. Motors.

Speed (R.P.M.)	68	204	612	817	1,224
Diameter over all (D_1)	225	212	165	154·6	124
Cost of non-effective material for zero length of Armature Core	5,100	4,500	2,700	2,400	1,550
Increase in cost of non-effective material with increased length	1,460	480	300	285	260
Cost of effective material	5,360	2,610	1,535	1,395	1,075
Total Works Cost	11,920	7,590	4,535	4,080	2,885
Do. by D × L rule	12,900	8,060	4,880	4,080	2,820

Table IV.

Estimation of Total Works Cost of 150 H.P. Induction Motors.

Periodicity (Cycles per Second)	21			63		
Synchronous speed (R.P.M.)	70	210	630	630	240	1,260
Diameter over all (D_1) ...	364	164	116	146	116	102
Cost of non-effective material for zero length of Armature Core ...	8,900	1,800	890	1,420	900	700
Increase in cost of non-effective material with increased length ...	660	790	560	300	350	440
Cost of effective material...	2,840	2,320	1,440	940	850	860
Total Works Cost ...	12,400*	4,910	2,890	2,660	2,100	2,000
Do. by D × L rule ...	6,700*	4,850	2,610	2,200	1,870	1,820

* This is an abnormal machine in every respect, but nevertheless closely follows lines of machines at present in operation. The D × L rule in so extreme a case gives far too low a value, and the value obtained by the analytical method is a trifle too high.

The same method has been applied as shown in Table IV. to the induction motors, $\frac{D_1^2}{15}$ shillings being taken as the cost of non-

effective material for zero nett length of armature core, and $0{\cdot}12\ D_1 \lambda_n$ being the increase in cost of non-effective material with increased length. It will be seen that a good agreement is obtained in all except the first case.

The costs as obtained in Tables III. and IV. are plotted in the curves of Fig. 12A, and it will be seen that the results lead to much the same conclusions as were arrived at by the D × L method and plotted in Fig. 12.

The principal conclusions arrived at in this paper are as follows:—

I. Induction motors are, for all capacities, considerably cheaper than continuous-current motors of equivalent ratings.

II. The general performance and the mechanical construction of induction motors improve rapidly with increasing rated speeds.

III. The general performance and the mechanical construction of continuous-current motors improve rapidly with decreasing rated speeds.

IV. The use of very low-speed induction motors and very high-speed continuous-current motors ought to be avoided whenever this is commercially practicable.

These conclusions are not new. They must, however, be much more widely understood if the electric transmission of power is to proceed on rational lines.

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Dr. SILVANUS P. THOMPSON: We have been so often indebted to Mr. Hobart for useful contributions to the designing of electric machinery that, when he gives us another paper, we are quite sure beforehand that there will be something of importance in it. The contrast that he has brought before us between the designs of a number of different machines, all to have the same rate of output, certainly emphasises several important features of design. We have known for long that small continuous-current motors were disadvantageous in many ways at high speeds. We have also known that in the case of induction motors, particularly three-phase motors, there were great advantages in that form of machine when high speeds were a necessity. All this has now been put upon a more intelligible basis by reason of the carefully worked-out examples that have been given us; and in this case also Mr. Hobart has not spared himself. I think we ought to recognise that he has given to the world useful information by putting these numerical tables at the end which enable us to check his designs and follow them from point to point.

In comparing together machines of one kind with those of another, it is useful to go back to first principles, to put aside for the moment empirical rules and formulæ, and to deal with rules and formulæ that can be looked upon as applicable in all cases. I venture to put upon the board a formula which I have found extremely convenient for comparing all kinds of electric machines, whether continuous-current,

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alternating, three-phase, or single-phase motors or generators. It is this :—

$$\frac{\mathrm{KVA}}{\mathrm{RPM}} = \mathrm{N} \times k \times d \times q \times p \div (1{\cdot}91 \times 10^{12})\text{; where N is the flux;}$$

k a coefficient (about 1·11 for alternators, 1 for continuous-current machines); d the diameter of the revolving part, in inches; q the specific load, or ampere-conductors per inch of periphery; p the number of poles.

If we are considering a machine of a given output at a given speed, we can see that we have a large number of variables to deal with. We might have few poles with a large flux from each pole, or we might have many poles with a small flux from each pole. We might have a small diameter of armature with a very heavy specific loading, or a small specific loading on a large diameter of armature. For alternating machines our number of poles is not variable; it is fixed by the revolutions per minute and by the frequency of the system —50 per sec., or whatever the frequency may be. Therefore it is not an independent variable. But it is clear we might apply all manner of variations between the other variables—the flux from one pole, the diameter of the armature, and the specific load. In a continuous-current machine the specific load is that which is mainly responsible for good commutation. If one puts more than 600 amperes per inch of loading on the armature, then the sparking becomes a serious question; so one keeps the specific load down if one wishes to be on the safe side in commutation. For alternating-current machines we know other considerations come in, which compel us to work within a certain range with respect to the amount of flux per pole. The question of armature reaction in alternators is governed mainly by the flux from one pole and the number of ampere-turns round that pole. In comparing these eleven machines of Mr. Hobart's design by the light of this formula and of other formulæ which can be deduced from it, one finds some interesting features. Taking first the five continuous-current machines, I notice that the largest of them—the one that goes slowest, with only 68 revolutions per minute—has a flux of about 15½ millions of lines from each pole, while the smallest, which runs at 1,224 revolutions and has only four poles instead of eight, has rather under four millions of lines; so that in the first machine there are eight poles about four times the size, as against four poles in the smaller machines, and these poles a quarter of the size of the large ones. The diameters do not vary so much. The largest one has a diameter about two-and-a-half times the diameter of the smallest one. The loading on the armature varies from about 560 amperes down to about 415 amperes per inch, so that they are not so very different from one another as to loading, but they differ mainly in the number and in the size of the poles, and the variations between one size and another are by this means taken into account. These speeds, which vary enormously from 68 to 1,224, you observe, are partly made up for by the changes in the design that are necessary and partly by making the armatures a little smaller—not so very much —for the quick-running machines, and by diminishing the number of poles and the size of the poles. When we come to the six induction

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motors, we find there are two lots, one for a frequency of 21 periods per sec. (which is a frequency practically unknown in this country), and the other for a frequency of 63 periods per sec. Here, too, the number of poles differs enormously. Taking the three first ones, Nos. 6, 7, and 8, have a periodicity of 21. The largest one has 36 poles, and the smallest one has only four poles, but the largest one which has 36 poles has only about 1 1-3 million lines for each pole, whereas the small one with four poles has five million lines. So the variation on these sizes has gone inversely, and instead of making the poles, as in the case of the continuous-current machine, smaller when less numerous, they are here much larger. Going to the other three machines working with the higher periodicity, the largest one has 12 poles, with a flux of 1,190,000, while the small one, with half as many poles, has a flux of 2,380,000 per pole; so that here again we find in the induction motors the size of the poles grows larger as the number of the poles is diminished. I do not know whether that is going to be a general rule of design for any given frequency, but it is a point, I think, that has not come out in any series of machines before. The specific loading on the armature, again, does not differ very much. There are several points that might be entered into that would interest designers of machines of this kind, particularly if one were to translate the formulæ so as to give the output in terms, not of the number of revolutions per minute, but of the peripheral speeds. I suppose all builders of dynamo machinery will be agreed on the point that you make a better use of your copper or iron, the higher the surface-speed. The specific utilisation of the materials, which is so important in the question of cost, is much more a question of surface-speed than of revolutions per minute. Taking armatures as they are built, with laminated constructions and copper conductors let into the slots, surface-speeds are usually seldom now below, shall I say, 2,000 ft. or 2,500 ft. per minute, and, except in very large machines, do not often go over 7,000—I am leaving out turbine machines for the moment, because they are a type by themselves. These surface-speeds, as I take them out from these machines, are somewhat significant. Taking the five machines of the continuous-current class, the first one has a surface-speed of only 1,040 ft. per minute, which shows that however good the design may be in other respects—and that it is not a bad design from the point of view of economy is quite clear—it has not a good specific utilisation of materials, simply because the surface-speed is so comparatively low. In the five machines the surface-speed is 1,040, 3,121, 6,400, 7,700, and 7,200 ft. per minute respectively, so that in these smaller machines there is a much higher surface-speed attained, which is favourable to economy of material. I should not be at all astonished at finding that the first machine will be a very dear one in cost, because its surface-speed is so very low. No doubt Mr. Hobart can say in reply to my comment on this point that it could not be anything else, and that a queer design like that (as he would himself call it) was not a very suitable design, and that if it had been made much bigger, that would have involved other difficulties, particularly the difficulty of the big commutator. Going to the other machines, which are more reasonable

as to surface-speed, the largest has 2,040 for its surface-speed, and the smallest one 5,720, the others being intermediate. There are many points of view from which these designs may be regarded, but I think I am expressing the opinion of all of us who are interested in this branch of the subject when I say that we feel very much indebted to Mr. Hobart for the trouble and pains he has taken to put before us this comparison, with all the data, by which we are able, not only to understand what he is doing, but even to dare to criticise him. Dr. S. P. Thompson.

Dr. C. V. Drysdale: I had not come with the intention of speaking on this paper, but as you have been good enough, Sir, to ask me to say something concerning it, I should like to follow Dr. Thompson in congratulating Mr. Hobart most heartily for having put such a large amount of information before us. I am sure very few people realise what an enormous amount of work this must involve, and Mr. Hobart having given it to us so freely is a matter which we ought to congratulate ourselves upon. In the first place, however, I feel that the size of the motor which Mr. Hobart has chosen is perhaps not so representative of everyday practice as a smaller one might have been. In ordinary workshop practice, for example, motors running from about 5 H.P. to 25 H.P. are much more common than larger ones, and certainly than motors of the size which Mr. Hobart has mentioned. Of course large motors are used for rolling mills or for large boring machines, and for pumping and blowing; but there is no doubt that the smaller machines form such a large proportion of the output of motors, that information concerning them as well would be of great value. Dr. Drysdale.

In dealing with the cost of the machines, Mr. Hobart's conclusion that the cost may be taken as proportional to the product of D and L is of great interest and importance. Mr. Hobart has, however, taken as the unit on which to base his comparisons the product of the diameter and length of the rotating part—the armature over the windings. I think perhaps it is a little unfortunate that, in taking these dimensions, he has adopted the dimensions taken over the winding instead of over the core. In recent design work we have been accustomed to deal with the core dimensions—for instance, in making use of the Steinmetz coefficient, which is so valuable in expressing the output of the machines in terms of core dimensions; I think perhaps if Mr. Hobart had adopted the same principle in expressing the cost of his machines, that would have helped considerably towards uniformity; and as we start all designing from the core dimensions, it would be a great advantage if these gave us an immediate idea of the cost of the machine. Moreover, one cannot help thinking that the core dimensions rather than the overall dimensions should be indicative of the cost when we come to consider both barrel and evolute connections, and Mr. Hobart himself admits that his formula applies to barrel windings only. Within the past few days I have had the opportunity of overlooking some of the machines we have at the Northampton Institute. There we have something between twenty and twenty-five small machines of various kinds, some of which are used in the shop for driving, and some of which are used for laboratory work. They are both direct and alternating-current machines, and we have been examining their dimensions. Perhaps one

Dr. Drysdale. of the principal things I have examined is this question of the cost. If you take a slice through the armature and take the length and diameter of the armature (and Mr. Hobart's results may very well be expressed by saying that he takes the cost of the machines at about 1s. per square centimetre of armature section), I find that small machines of from about 2 to 10 H.P. give a fairly constant cost of about 2s. 6d. per square centimetre of core area—not of the area taken over the winding, but of the core area itself. I should mention that this is the net selling cost, not the factory cost, as has been taken by Mr. Hobart. If we take the ordinary Steinmetz formula for the armature dimensions, viz., $d\,l = \sigma$ K.W., where σ is the Steinmetz coefficient, it follows that the cost of the machine in shillings $= 2{\cdot}5\,d\,l = 2{\cdot}5\,\sigma \times$ K.W. As an example for large machines, where σ has a value of about 20, we see that this states that the cost of the machine is about £2 10s. per k.w. I cannot help thinking that this comparison of the cost with the Steinmetz coefficient would be of great value. As I venture to think that a knowledge of the constants of small machines is of value, and they are not easy to obtain, I include a table showing the various values for the machines we have tested. It will be noticed that there is a very close relationship between the cost of the machine per kilowatt and the Steinmetz coefficient.

The main question that is before us this evening is the speed of the motor. The general conclusion from the paper seems to be that the induction motor is on the whole preferable for the high speeds, while the direct-current motor shows up better on the low speeds. On that point I should like to make one remark, as we are hearing very much lately about the question of the speeds of motors for various purposes: I cannot help thinking that that is a question where the mechanical engineer ought to come in a good deal more than he does. It seems to me that the gaining of low speeds by electrical means is, as a rule, a very expensive method of going to work, because we have to put in a large amount of laminated iron and copper and insulation, which are expensive materials; whereas, on the other hand, if we can go to high speeds with less costly motors and get satisfactory reduction gears of sufficient range, it should be a far more practical way of going to work. It must be remembered that it is only in comparatively rare instances that small motors can be used for direct driving. If we wish to drive a countershaft at from 100 to 150 r.p.m., we are obliged to mechanically reduce by belt or gearing in any case, and the use of low-speed motors with gears of from 3 or 4 to 1 is really making use of a double reduction gear in which the first reduction is gained electrically by means of costly electrical materials, instead of reducing the speed by inexpensive gearing directly from a high-speed motor. I do not mean to say for an instant that mechanical means of reducing speeds are thoroughly satisfactory, but I think that that is one of the things which might be looked to, even more than it has been up to the present. In connection with that, I may state that there is a reduction gear that has been lately brought forward, and I do not happen to have seen that it has been very much referred to in the electrical papers. I refer to the gear that has been brought forward by a firm in Bristol, and which seems to be remark-

Dr. Drysdale.

ably efficient and capable of being used on induction machines. The reduction is from 4 to 1 up to 20 to 1; I have had no opportunity of testing it myself, but the efficiency of it from independent tests seems to come out to the order of between 90 and 95 per cent. If that is the case, I am inclined to think that the aiming for very low speed designs is somewhat of a mistake. I think what we ought to do is to try to get a satisfactory reducing gear, which I hope by the method I have just mentioned has been obtained, and that we ought also to try and make variable ratio gears to some extent, in order to vary the speed. Under these circumstances there is no objection to using induction motors, although their starting properties are not so good. The principles of this gear, no doubt, must have been well known a long time ago, but the arrangement of it is simply this: you have an outer case which has a gear cutter toothed on the inner periphery; the driving shaft is on the wheel in the centre, and you have two gear wheels which are toothed on the outer and inner periphery, the driven shaft being driven by those two. The whole thing is perfectly symmetrical. The external part of the gear is simple, the driving and driven shafts being in the same line. If we call r_1 the radius of the centre wheel, and r_2 the radius of the driving-wheels, the gear ratio is evidently

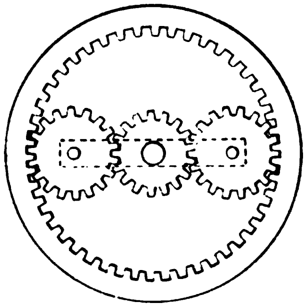


FIG. B.

$$2\left(1 + \frac{r_2}{r_1}\right).$$

It seems to me that that arrangement, which is extremely compact, will give satisfactory and highly efficient drives, and under those circumstances I do not see that there is any reason why we should not use the highest speed motors. There is one further point: In the case of single-phase motors, and so on, where the starting properties are bad, you can work extremely well with this gear, for the reason that the outer case, if allowed to be free, will revolve, and the driven shaft can be connected to whatever ratio you want to run, and you can start the motor perfectly light, whatever may be the torque on the driven spindle. You can put the brake on the outside circumference, and the torque can be put gradually on the motor after it has got up its speed.

Finally, we have had a great many objections to induction motors on account of absence of speed regulation. But again I venture to think that electrical speed regulation should be avoided as far as possible except over a limited range. What we want is lower speeds with increased torque and no rheostatic losses, and a variable speed gear is the correct thing for the purpose. Of course this has been realised for a long time, but it is only lately that with automobiles mechanical engineers have turned their attention seriously to this matter. It is realised that in this case we require to have a high-speed

Dr. Drysdale. and constant-speed engine and to change our speed mechanically, and I think that with motors we should look at the matter in the same way, and unless we are specially designing for direct coupling, etc., we should aim at motors having the highest economy irrespective of speed, and do the rest mechanically. The induction motor would then take the place it truly merits.

Mr. Meyer. Mr. H. S. MEYER : While I agree with the previous speakers on the value of Mr. Hobart's paper as such, I cannot admit that all the facts brought forward are consistent with the results obtained in practice. Mr. Hobart attempts to cover an excessive range of speed, and thereby detracts from the value which his conclusions have for the ordinary commercial range of speeds for direct-current and alternating-current motors. While it is quite possible to compare direct-current and induction motors of commercial speeds on their merits, it is very difficult to extend such a comparison to abnormalities such as motors running at 68 r.p.m., since their performance and cost must either be estimated entirely or based on one or two examples.

In general, I am very sceptical of so-called theoretical cost figures. The cost depends on so many variables and constants added together, that a simple formula, such as given by Mr. Hobart, must lead to figures of very little practical value. To deal with the induction motor in particular, it is quite evident that a formula like Mr. Hobart's can only lead to correct results as a matter of chance, no consideration being given to the more rapid increase in factory costs with increase in diameter. Here I refer in particular to the additional costs due to the difficulties in handling larger pieces, and due to the larger capital invested in the bigger size of tools; also to the question whether the windings are hand-wound or form-wound, and obtained by high-paid or low-paid labour, etc. What makes Mr. Hobart's formula also theoretically doubtful, is the way in which the pole pitch is considered in his formula. For instance, taking a diameter of 20 in. and a length of 5 in., and winding the same carcass for 6-pole and 12-pole (a range of poles which is very often used on the same frame), Mr. Hobart's formula will show that the motor with the higher number of poles is about 30 per cent. cheaper than a machine with the lower number of poles, the figures obtained being 247 and 173. This is obviously wrong, as a machine with a higher number of poles should, if anything, be more expensive due to the increased number of connections required in the winding, and also the greater difficulty in the winding itself. I have found that a better approximation to the factory costs of standard and semi-standard induction motors is obtained by using a formula where the cost is equal to $D^{1.8} \times L$. This considers the greater difficulties in handling large machines, and avoids the contradictory results for different number of poles, which are brought out if the pole pitch is used as in Mr. Hobart's formula. However, also for this formula, I cannot claim accuracy over a very wide range of designs, nor for machines of different make.

Now in regard to the question of speed. First of all excessive speeds should be eliminated, and only a reasonable range should be considered. This will enable us, with induction motors, to consider the same

NES.

Mr. Meyer.

ripheral Speed.		£ per K.W.	Cost	
er .	Cm. per Sec.		Per sq. inch $d \times l$.	Pe
0	1,020	...	...	
0	1,500	7·1	19·9	
0	711	12·4	15·0	
0	1,145	7·3	13·9	
0	915	14·0	14·3	
0	885	12·5	12·35	
0	802	13·4	17·3	
0	712	17·5	20·2	
0	890	14·8	20·3	
0	1,370	18·7	13·65	
0	1,265	18·4	15·05	
0	864	14·3	27·6	
0	1,040	11·75	21·4	
0	1,725	10·5	19·65	
0	1,370	12·5	22·3	
0	1,058	6·9	21·2	
0	706	9·0	17·5	

ORS.

0	2,950	...	...
0	1,765	12·1	16·85
0	1,850	9·25	15·8
0	1,680	7·5	16·3

Dr. Drysdale.

Mr. Meyer.

frequency throughout. The introduction of two frequencies which differ in the ratio of 1 : 3 is very misleading, and adds to the complication of the problem, which in itself is very complex. I should like to draw the limits of commercial speeds of a 50-H.P. motor from about 300 to 1,000 r.p.m. and a 10-H.P. motor from 400 to 1,500 r.p.m. Mr. Meyer.

I have plotted some curves which I am glad to offer for publication in the Proceedings, giving the relation between direct-current and alternating-current constants within the above range of speed for a 10-H.P. and 45-H.P. motor; they are not based on any theoretical consideration, but on actual results obtained on a great number of motors built by the British Thomson-Houston Company. The curves

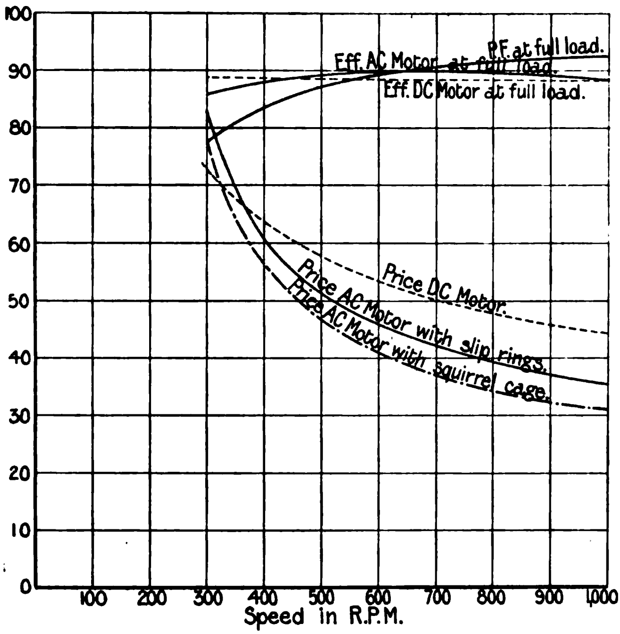


FIG. C.—Comparison between 45 H.P. Induction Motor and 45 H.P. Direct-current Motor.

show results quite different from those obtained by Mr. Hobart. For instance, Fig. C, representing the comparison of 45-H.P. motors, shows a difference in price of 24 per cent. in favour of the slip-ring induction motor, and 42 per cent. in favour of the squirrel-cage induction motor or, for an average, a figure of 33 per cent. against Mr. Hobart's 50 per cent. The intersection of the cost curves for D.C. and A.C. occurs at 375 r.p.m., while in Mr. Hobart's Fig. 12 the curves seem to diverge for lower speeds, which certainly is wrong, and from this point of view the curves in Fig. 12A seem more to approach the actual facts. The efficiency curve given in my Fig. C, shows a maximum at about 700 r.p.m and dro already 2 per cent. at 1,000 r.p.m. Quite different from Mr. Hobart's statements are the results contained in my Fig. D,

Mr. Meyer. where the same comparison is made for 10-H.P. motors. Here the direct-current motor is about 10 per cent. cheaper when compared with the slip-ring motor, an intersection of the curves occurring somewhere near 1,800 r.p.m., and of the same cost when compared with the squirrel-cage motor. The intersection occurs here at about 1,000 r.p.m. The maximum efficiency of this size occurs at about 1,000 r.p.m., and a drop of 2 per cent. is noticeable at 1,500 r.p.m.

In connection with the above curves, I must take exception to Mr. Hobart's general statement, that the difference in cost between squirrel-cage and slip-ring motors could be taken as about 25 per cent. and this value he used for the 150-H.P. motor. I have plotted a curve, E, in which the difference in cost between squirrel-cage and slip-ring motors is shown, as a function of the rotor diameter, and it is

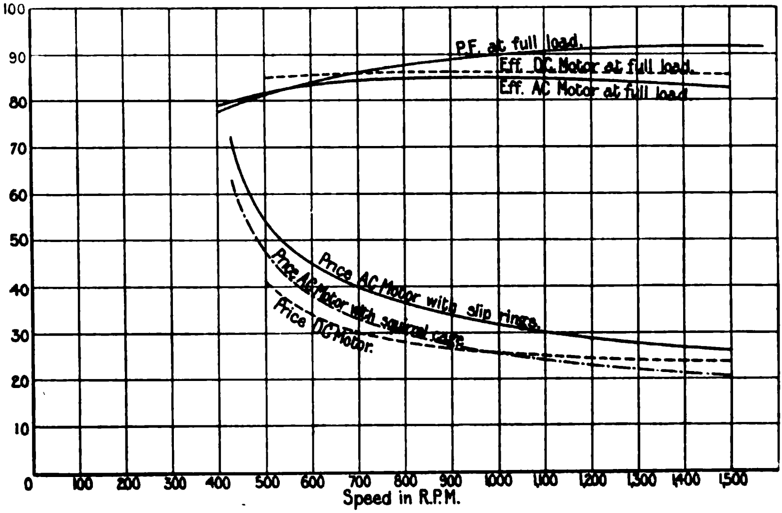


FIG. D.—Comparison between 10 H.P. Induction Motor and 10 H.P. Direct-current Motor.

quite obvious that the percentage cost will vary considerably with the size of machine. While a figure of 25 per cent. should be about right for smaller sizes, it seems excessive for a 150-H.P. motor, considering that the slip-ring rotors of such sizes will have mostly a bar winding, and therefore the difference in cost should be small as the curve shows, about 8 or 10 per cent.

The next point to which I wish to refer, in a few words, is the formula for leakage in induction motors, to which Mr. Hobart refers in his paper. Here, again, I must say that experience shows that it is impossible to represent the actual leakage in induction motors by a simple formula such as given by Behrend and modified by Hobart. I have checked his recommendations on a great number of designs, and find results of very little practical value. The problem is of such a nature, that a general law—while it may happen to approach the conditions in

a number of normal machines—will generally fail in abnormal machines, and it is here that it is most necessary to foresee the performance. However, I would exceed my time if I were to go into details. Mr. Meyer.

Further I cannot quite agree with Conclusions I. and II. in Mr. Hobart's paper.

Conclusion I., as shown by the curves, based on actual costs, cannot be substantiated in the broad sense expressed in the paper, but will entirely depend on the sizes used. As to Conclusion II., the general performance and the mechanical construction of induction motors improve with increase in rated speeds, as long as the above-given range in speed is not surpassed, but, with excessive high speeds, the efficiency, as well as the mechanical construction, particularly of slip-ring motors, decreases rather than increases in quality.

With the 4th conclusion, I must agree as long as the excessive range in speed is considered; but, within the commercial limits

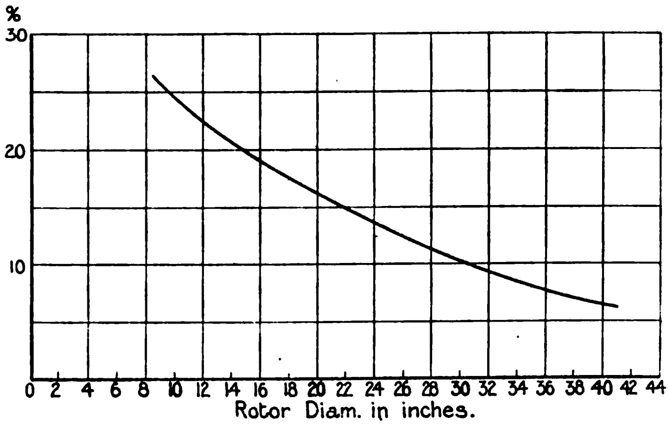


FIG. E.—Percentage Reduction for Squirrel-cage on price of Slip-ring type.

referred to above, the direct-current motor at moderate speeds, and the alternating-current motor at slow speeds, will be entirely satisfactory. In regard to cost, the high speed will always be more favourable, both for alternating-current and direct-current machines, and I think Mr. Hobart goes somewhat too far in his preference for the very slow-speed direct-current machine. While it must be admitted that it is easier—as far as commutation goes—to design a good direct-current machine at a slow speed, it is, on the other hand, with our present experience, readily possible to design a good direct-current machine for high speed. As an example, I need only refer to the turbine-driven direct-current machines, where 300-k.w. machines and more have been designed to run sparklessly at 1,800 r.p.m. without the use of compensating windings. Of course this must be considered a special case, but the tendency for high-speed D.C. apparatus, and the consequent reduced cost, cannot be stopped on the ground that greater

Mr. Meyer. care and experience in the design are required. An analogous case has been experienced with the steam engine, where the question of high speed *versus* slow speed presents a problem similar to that with which we are confronted in direct-current machines.

Mr. Stoney. Mr. GERALD STONEY: I did not propose to speak to-night, but, having been asked to, I would like to mention that a gear similar to the one which Dr. Drysdale described was used by Mr. W. T. Shaw, of London, in the crypto two-speed gear for bicycles and tricycles about twenty years ago, and is still used in the Hub two-speed gear and the Raleigh three-speed, as well as on motor tricycles. With reference to motors and dynamos, which, of course, are interchangeable, my chief experience has been with the high-speed dynamos driven by turbines. As Professor Thompson points out, as you get up in speed, the ordinary commutation constants get worse and, as a result, in order to get fixed commutation, you must have a compensating winding of some sort, to compensate for the armature reaction, but with suitable compensation winding, you can get fixed commutation up to, say, 100 or 150 per cent. overload. Recently we have made large turbine dynamos which, for traction work, would stand heavy overloads with no movement of the brushes. That was impossible until quite recently, and it is only by having winding to compensate for the armature reaction that it is possible. The same applies to alternators. Turbine alternators have generally either two or four poles, and in them the size of the pole is large. As a result, you have a large armature reaction, and you have to compensate for that by powerful field magnets, the magnetic reluctance necessitating large air-gaps as a rule, and also magnetic saturation in some part of the circuit; but with suitable conditions very good regulation can be obtained—in fact, the regulation of turbine alternators in many cases is superior to that of the slow-speed alternators—there having been drops of only from 2 per cent. to 3 per cent. in some of the machines that Messrs. C. A. Parsons & Co. have made, between full load and no load, with constant speed and constant exciting. That has come upon us in one or two cases as a considerable surprise, but, in some ways, regulation is rather easier with high-speed alternators than with low-speed alternators. I think that we must thank Mr. Hobart for the most able and instructive paper he has given us. I have never before seen such a complete table of costs in relation to motors, and such are of great value to our members.

Mr. Williamson. Mr. A. D. WILLIAMSON (*communicated*): I think that the members of this Institution owe a debt of gratitude to Mr. Hobart for the papers he prepares from time to time on the subject of machine design. The paper now under discussion is of a novel character, and is mainly useful as an indication of the effects of extreme values of one of the variable factors. The factor which Mr. Hobart has varied is the speed, and he has taken extremes well outside the range of ordinary practice. A motor of 150 B.H.P., if left to the selection of the engineer who had to apply it to a useful purpose, would probably be designed for a speed between 200 and 600 r.p.m., *i.e.*, the second and third alternatives analysed by Mr. Hobart. The lowest speed of 68 r.p.m. would make

Mr. Williamson.

the cost prohibitive, and the highest speed would be very difficult to apply to any kind of machine. It appears that for medium speeds the continuous-current motor is quite the equal of the induction motor from the point of view of its behaviour, apart from that of cost. I cannot criticise any of Mr. Hobart's designs of the induction motors, but I think his continuous-current machine at 204 r.p.m. is a very expensive design. The constants would permit of a very good machine with two turns per segment and much smaller commutator without exceeding the usually specified temperature rises. Comparing the two classes of machines over the range of practical speeds, say from 200 to 800 r.p.m., there appears to be little to choose between them in efficiency at full load, but, at reduced loads, the induction motor gains. This gain is, to my mind, neutralised by the very indifferent power-factor at partial load, particularly with the higher-frequency motors. The motor is not the only thing to be considered, the provision of cables for the wattless current is a very serious point when one has to serve a number of motors, working perhaps at 70 per cent. or 80 per cent. of full load, and at a power-factor of about 0·8. Although the figures given in the paper are of great interest, it is, as Mr. Hobart states, very rare to find speed a determining factor in choosing between the two classes of motors. The choice is usually forced upon the engineer before he gets as far as considering the question of speed, and speed is chosen to suit the type of plant adopted. It has become fashionable to adopt induction motors lately for factory driving, for some reason which is not very apparent. Many cases exist where the pressure is the same as would have been adopted for continuous currents, so that no saving in copper can be claimed; but, as the wattless current has to be provided for, there is actually a *waste* of copper with no compensation. The speed control, starting effort and usual rated speeds of the induction motor do not lend themselves nearly so well to machine driving as do the corresponding properties of the continuous-current motor. This may look like an attempt to dig up the old controversy, A.C. versus D.C., but I think it is really within the limits of the discussion. To secure good lasting results with motor-driven machinery, speeds must be moderate. I have often been checked in the application of variable-speed motors by the impossibility of transmitting the power of, say, a 40-B.H.P. motor through efficient and quiet gearing at a speed of 800 or 900 r.p.m. A natural and convenient range for a variable-speed motor is from 300 to 900 or from 250 to 750 r.p.m., and, if it were not for the mechanical part of the transmission, this range might be increased in an upward direction. Having had opportunities from time to time of comparing the prices of alternate-current and continuous-current motors, I cannot help thinking that Mr. Hobart's 150-B.H.P. comparison gives an impression that the difference in cost, other things being equal, is greater than the average differences found in commercial practice. Perhaps this may be due to the designs of the induction motors in the paper being more economical than those of continuous-current motors; but if Mr. Hobart in his reply could state a rough figure for a ratio of cost for equal *output*, as he has done for

Mr. Williamson. equal *dimensions*, I am sure it would add value to his excellent and suggestive paper.

Mr. McLeod. Mr. R. S. McLeod (*communicated*): This is a most interesting paper, and particularly valuable for the large amount of data given of the various designs. Other designers would no doubt have got out slightly different proportions for the machines, but with Mr. Hobart's main conclusions (particularly with regard to slow-speed induction motors) no one will be inclined to disagree. The rise in reactance voltage is very marked in the high-speed direct-current machines, and would have been more so if greater differences of diameters had been taken; for, as pointed out by Mr. Mavor a year or two ago, with one turn per commutator bar and constant induction in the air space, the reactance voltage is simply inversely proportional to the armature diameter for constant output. On the other hand, if a comparison had been made on a machine of smaller output, the reactance voltage would have been more constant, as the high-speed machines would have had one or two turns per commutator bar, and the slow-speed machines several. Although there is such a marked divergence between the influence of speed on the D.C. and A.C. machines, yet they have one or two points in common. The first is the high copper loss of both types at slow speed; the second, the bad influence of a high periodicity. The A.C. machine has a marked drop in power-factor on changing from 21 periods to 63, and the D.C. machine is good at a slow speed, simply because one is enabled to drop its periodicity more or less in proportion to the speed. The A.C. motor would have been quite good if its periodicity could have been reduced in like proportion. There is one question I should like to ask the author: Is not the 4-pole D.C. machine somewhat overloaded? It has the same periodicity and practically the same size pole as the 6-pole motor, and one would therefore expect both to have the same output per pole, giving the 4-pole a total output of two-thirds of that of the 6-pole. Manufacturers should be specially grateful to Mr. Hobart for two such simple and accurate methods of checking the cost of a machine as those which he has given us.

Mr. MacLaren. Mr. M. MacLaren (*communicated*): I have read Mr. Hobart's paper with great interest, and I believe this question of the speed of motors as determining the type of plant to be installed should receive greater consideration than it does at present. I agree entirely with Mr. Hobart as regards the great superiority of induction motors over direct-current motors for high-speed work, as well as for medium-speed drives where a variable-speed motor is not required. At the same time, I think Mr. Hobart has made out rather too strong a case for the induction motor. For example, from Table I. it would seem that the total material employed for the various direct-current motors is about normal, and yet the efficiencies, especially on the higher-speed motors, are very much lower than those obtained by most of the leading manufacturers. On the other hand, the induction motors have a somewhat higher efficiency than would be expected, and this seems to have been obtained at the expense of the power-factor.

The method of comparing the costs of various motors by taking the principal dimensions of the motor is certainly very convenient, but it

seems to me that it could not apply, even approximately, in comparing motors which differ so widely in their construction. This method might be used satisfactorily in the case of a line of direct-current motors, in which the same general type of construction is employed, and which does not differ very greatly in size. It might also apply, under similar conditions, for induction motors, where the number of poles remains approximately the same. I would expect, however, that it would not hold when comparing the relative cost of a motor of a given output operating at, say, the extreme speeds of 68 r.p.m. and 1,224 r.p.m. discussed in this paper, as the type of design would necessarily be very different in the two cases. I would also expect that the relative cost of the labour on the machine to the total factory cost would affect the results, so that the same law would not hold for a small motor, in which the labour-cost is a large percentage of the total cost, as it would for a large machine in which the material is the principal item of expense. Mr. MacLaren

Mr. FREDERICK USSING (*communicated*): I find Mr. Hobart's comparisons most interesting and instructive, but I have not had the time, personally, to draw a direct comparison between induction and continuous-current motors, and I wish, therefore, only to submit a few remarks. The formula $\left\{ \begin{matrix} K_c D L \\ K_i D L \end{matrix} \right\}$ as a basis for comparison of cost of continuous-current and induction motors gives, no doubt, good values. As a basis for figuring approximate factory costs, I believe the formula correct inside wide limits when dealing with a factory fitted with modern machinery able to cope with the largest units at present in use, but in factories of moderate size, working with old as well as with modern machinery, the limits inside which the costs compared on the basis $\left\{ \begin{matrix} K_c D L \\ K_i D L \end{matrix} \right\}$ holds good will be narrow, and I am inclined to think that the factor "D," in most cases, ought to have a certain exponent depending on the factory, though this exponent will hardly ever be more than 1·5. Mr. Ussing.

The principle of design used for the continuous-current motors, specified in the paper, agrees with my own experience. The conclusions arrived at are rather discouraging for the designer of high-speed continuous-current motors; the speed limit is, at all events, reached only too soon; but I find the curves in Figs. 17 and 18 unfavourable, and indicating a too low speed-limit. In Fig. 17 several curves for different capacities would perhaps have been more instructive in view of the fact that the difficulty of obtaining good reactance voltages increases with the output, assuming constant speed. I find that considerably higher values for reactance voltage (using Mr. Hobart's formula) are permissible when using parallel windings; also that, for the motor-speeds at present in use, the curve in Fig. 18 gives values which are too high. A commutator peripheral speed of 18 metres per second for a 150 H.P. 600 r.p.m. motor appears unnecessarily high.

Dr. WILHELM HESS (*communicated*): For the practical engineer it is always a valuable assistance to use, for roughly estimating the price of a machine, a formula such as that given by Mr. Hobart in his very interesting paper. Dr. Hess.

Dr. Hess. As the author points out, the factor k will be fairly constant for a given voltage, but in my opinion it would have been of great value to compare the two systems with respect to varying voltages. I find that a curve with voltages as ordinates and factors k as abscissæ would be a necessary improvement on the formula. For induction motors the curve would be a curve which at first ascends slowly and, with a voltage of about 2,000, ascends more rapidly. For continuous-current motors the curve will be a curve starting with a minimum point at a moderate voltage, ascending for lower as well as for higher voltages, assuming a definite speed.

With respect to the ratio $R = \frac{K_c}{K_i}$, I would suggest that the factor R ought to be varied for different ranges of output. Thus, for example, from 1 H.P. to the maximum, R will vary from 1·3 to 1·7.

The comparison of the continuous-current motor C, in Table I., and the induction motor with 21 cycles and 4 poles, in Table II., which is just suitable for railway work, shows once more the superiority of the induction motor for traction purposes, as far as the design of the motor is concerned. The number of revolutions for both motors is about the same, as well as the weight and price. When we reduce the continuous-current motor from 6 to 4 poles, the weight and also the costs will not be reduced. But besides the better efficiency of the induction motor, 2·5 per cent., we have then still the great advantage of employing high voltage.

Mr. Esson. Mr. W. B. Esson (*communicated*): This paper, like all Mr. Hobart writes, is very interesting. The main proposition of the author is that the speeds at which motors have to run may constitute the factor which chiefly determines the system to be adopted in order that the requirements may be met at minimum cost, and it may be taken that, with certain limitations, the case has been proved. The first limitation comes from the frequency, and it does not seem that the same weight should be given to the lower frequency as to the higher. This arises from the fact that a frequency of 21 is quite unsuitable for the lighting which is generally associated with motor driving, and the cost of the motor generators, or whatever transforming devices may be required for the lighting portion of the installation, might from the cost point of view turn the scale against the low-frequency motors, or at any rate reduce the advantage shown by one system over the other.

Mr. Hobart in his conclusion sums up accurately the case for alternating *v.* continuous current as regards the motors, but, in deciding in favour of one system over another, it is also necessary to take into account the cost of generators, wiring, starters, and all other equipment, and which side the consideration of these further factors would favour, depends on circumstances. In working out his examples, the author confines himself to one size of motor, and though the results may be considered indicative of how the advantage will lie, it must be remembered that most installations have a mixture of big and little motors, several different sizes running at different speeds, and this, together with the presence or absence of the necessity for speed-variation, would influence the decision as to what should be installed.

Dealing with design, Prof. Silvanus Thompson shows great ingenuity in devising new formulæ, but I cannot see that in his present venture he gives us anything more than is given by the old $D^2 L R \phi$ expression. The latter is not empirical in any sense, as it takes into account the field density, pole area, conductors on armature and current through them, giving to all these factors their proper value in one coefficient ϕ, a very usual thing in engineering formulæ. It is not, apparently, recognised that the expression above-mentioned applies to induction motors just as to continuous-current motors. The value of the coefficient ϕ in this case depends on the slip, on the number of conductors on the rotor, on the induction in the air gap, on the pole-pitch, and other constructional details; and has for small machines, of course, a smaller value than for large ones. This arises chiefly from Mr. Esson.

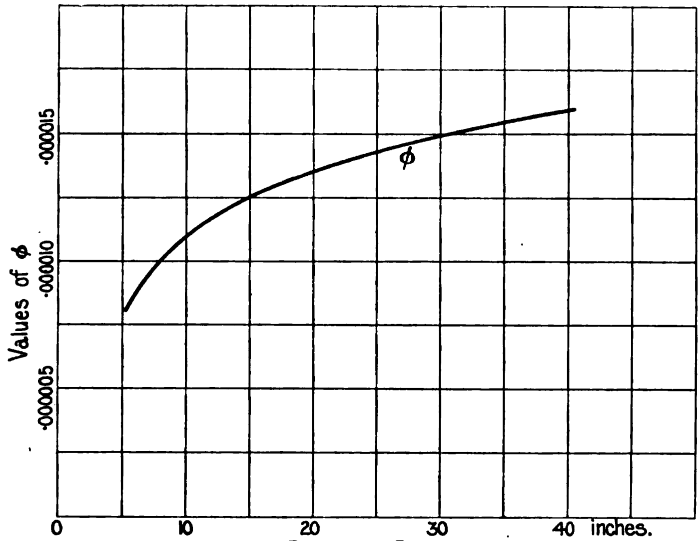


FIG. F.

the fact that in the latter the pole-pitch is smaller and the gap induction less; in the smallest size of motor, for instance, the pole-pitch will be only about 4¾ in., while in motors of 150 H.P. it will reach 10 in. or so. This means in effect that the coefficient increases in value with the diameter of the rotor, and in figure F is given a curve showing the relation between ϕ and the diameter for normally-designed motors. The coefficient is chosen to give horse-power thus: H.P. = $D^2 L R \phi$. It will be seen that the output of each of Mr. Hobart's sixty-three cycle motors is, as nearly as exigencies of design will allow, proportional to $D^2 L$, with the coefficient, in each case, of the same value. The reason why, in the examples given, the value of the coefficient does not diminish as the diameter of the rotor is reduced, is because for all these sizes the author selects a diameter which gives the

Mr. Esson. same pole-pitch. But in each case the coefficient is high, reaching ·000024 as against ·000016, the highest shown on the curve, and presented by the best European practice. In the three machines referred to, the ampere-bars on the stator per in. of circumference are also similar, but reach close on the high figure of 800. This is from 30 to 40 per cent. greater than the usual standard practice, while the field density in the air-gap is also above the normal. As figured, these motors offer such deviations from normal types as would necessitate the complete designs being carefully looked into in all their details before one could say whether they would be quite satisfactory. But whether they would require modification or not, they serve very well to bring out the main point of Mr. Hobart's paper.

About the relation between the cost and D L, I need not say anything. A curve showing the relation may approximate a straight line or it may not, but I do not think it matters in the least. It would certainly be handier for estimating purposes if it were a straight line, but, apart from that, it appears to me to be unimportant.

Mr. Kilburn Scott. Mr. E. KILBURN SCOTT (*communicated*): Mr. Hobart's paper is another nail in the coffin of the continuous-current machine, and when at last we get it decently interred we shall wonder how it was that such a freak held the market so long. Even now it is safe to say that where there is one firm making induction motors there are a dozen making the other type, and yet the induction motor is *par excellence* the motor for the small shop. The writer saw some being made recently in a foundry by ordinary fitters, and although there was not a single electrically-trained man in the place, or any testing facilities, yet the motors worked perfectly when delivered. The ideal motor is one made entirely of copper steel and micanite, for all such unmechanical materials as tape, varnish, fibre, and wood must go; they have been used far too long as it is. Furthermore, the motor and its auxiliary apparatus must be capable of working wherever a steam engine will work, that is to say, in wet and dirty situations. These conditions are more likely to be met by the induction machine. The cost curves (Figs. 12 and 12A) are interesting as showing how much more favourable the induction motor is to the buyer's pocket, which is, after all, the main thing to be considered. Although prices have dropped within the last few years with alarming rapidity, it yet takes a great deal to convince the ordinary buyer that the large initial expense of an electric power installation is going to be to his advantage. Every drop in price is therefore a distinct advantage to the electrical profession, as it brings so many more buyers within the range of our activities. The bedrock price of any article is the price at which it can be made by a private concern having no white elephant in the way of over-capitalisation, large sums paid away for patent rights, or an expensive staff, etc. This is where, the writer believes, the small, well-managed private concern will come in and set the pace. At present, unfortunately, many English firms continue to potter along with out-of-date designs and plant. In comparing prices Mr. Hobart, of course, deals with the motors only; but no motor can be considered complete by itself. A real commercial comparison must include the starting apparatus. If this is done the superiority of the

Mr. Kilburn Scott.

induction motor is very pronounced, for it does not require the molly-coddling devices which are such a feature of the continuous-current machine. Mr. Hobart's tables show a much smaller amount of copper required by the induction motor for the same horse-power and speed, and in order to throw up this fact more prominently the writer has tabulated his figures. It will be seen that with the exception of the first column, which is for motors at 70 revolutions (and which appear to be in error), the amount of copper in the induction motor averages less than half that required for the continuous-current machine. With such an expensive and fluctuating material as copper this is an important consideration for manufactures.

	70 Revs.	210 Revs.	630 Revs.	630 Revs.	940 Revs.	1260 Revs.	
	£	£	£	£	£	£	
Cost of Copper -	1400	820	480	430	324	282	Induction Motors
Cost of Laminat'ns	1440	1500	960	510	530	575	
	68 Revs.	204 Revs.	612 Revs.		817 Revs.	1224 Revs.	
	£	£	£		£	£	
Cost of Copper ...	1940	1450	920		840	700	Continuous-Current Motors.
Cost of Laminations and Cast Steel	3420	1160	615		555	375	

Perhaps of all the information which Mr. Hobart has so painstakingly presented, the particulars dealing with efficiency at various speeds are the most informing. Thus, in Fig. 14, at *full load* the efficiency curves of continuous and induction motors cross, and from being $2\frac{1}{2}$ per cent. lower at 70 revolutions the induction motor is some 4 per cent. higher at 1,300 revolutions. At *half load* the induction motors give about 89 per cent. over a wide range of speed, whilst the continuous current drops from 87 per cent. at lowest speed to only 81 per cent. at 1,300 revolutions. Owing to the speed of an induction motor being governed by the periodicity of the circuit, it is conceivable that gearing will have to be resorted to more frequently in applying them than would be the case with continuous-current motors. The superior efficiency will, however, much more than cover any additional losses due to such gearing. As a matter of fact, the idea of doing away with gearing at every opportunity and at all cost is quite a mistaken one. It is much better to judiciously introduce gearing of the right kind and amount. For example, it is better to have all the motors in a factory of the same size and speed, and make the changes on to the various machines by gearing than it is to have almost as many different motors as there are speeds. The very fact that the speed of an induction

Mr. Kilburn Scott. motor cannot be chopped and changed about by every T.D. and H. is, indeed, a distinct point in its favour. Personally, the writer has never yet met a case of applying a motor to a machine which could not be met by the induction motor with a certain amount of gearing, either simple reduction or change gearing. Of course this question of gearing must be tackled properly; it is essentially millwrighting work, and requires a millwright's training. It is as great a mistake to apply a patent Jack-in-the-box jim-jam gear as it is to employ gear-wheels where plain belting would do, or *vice versâ.*

Mr. Hobart. Mr. H. M. HOBART, in reply, said: Dr. Thompson spoke of the high loading of the periphery of the armature as being prejudicial to commutation. I am not in agreement with Dr. Thompson's views on that matter, because I believe that it is exactly on those lines that we can tremendously cheapen dynamo-electric machinery, especially the continuous-current dynamo. I am convinced that continuous-current motors of something like half the D × L of those given in the table—at least in the lower speed ranges—can be produced by this means of employing much higher values for the ampere-conductors per centimetre of armature periphery and without running into any commutation troubles whatever. The time is not yet quite ripe for this, as many traditions and prejudices have yet to be overcome. It is, however, on these lines that improvement in the design of the continuous-current dynamo will proceed. Another point in which I am inclined to differ with Dr. Thompson relates to the peripheral speed. Of course, if it was only a question of the net effective material, I should agree perfectly with Dr. Thompson that the higher the peripheral speed the cheaper would be the machine; but when you have a given size to design, and the highest practicable peripheral speed leads to exceedingly narrow machines, then obviously the mechanical costs constitute a large percentage of the total cost of the machine. But it is true in a certain sense, and one gets the very cheapest machine per unit of output, in those cases in which a high peripheral speed is accompanied by a wide machine. These conditions come in recurring sizes and voltages and speeds. But taking the total cost, including the mechanical costs and the costs for material, a machine of very low peripheral speed will often be the cheaper, and will make the best use of the total material and labour required.

From my formula,

$$\text{Total Works Cost} = K \times D \times (\lambda g + 0{\cdot}7\, r),$$

and Esson's formula,

$$\text{“Output Coefficient”} = \frac{\text{Watts Output}}{D^2 \times \lambda g \times \text{R.P.M.}}$$

expressed as follows:—

$$D^2 \lambda g = \frac{W}{\phi \times R},$$

we may for any value of ϕ, derive the diameter corresponding to the cheapest machine.

Thus, expressing D and λg in centimetres and taking ϕ equal to 0·0010, a fairly representative value for good designs of induction motors of from 15 H.P. to 150 H.P. output, Esson's formula becomes— Mr. Hobart.

$$D^2 \lambda g = 1{,}000 \times \frac{W.}{R}$$

Denoting Total Works Cost in shillings by T.W.C., we now have two equations—

$$\text{T.W.C.} = K \times D\,(\lambda g + 0{\cdot}7\,\tau) \quad \ldots\ldots\ldots \quad (1)$$

and

$$D^2 \lambda g = 1{,}000 \times \frac{W}{R} \quad \ldots\ldots\ldots \quad (2)$$

Let N = number of complete cycles per second, then

$$D = \frac{120\,N\,\tau}{\pi\,R} = 38{\cdot}2\,\frac{N\,\tau}{R}.$$

We can then eliminate D from formulæ (1) and (2), and obtain the following formulæ :—

$$\text{T.W.C.} = \frac{38{\cdot}2\,K\,N\,\tau\,\lambda g}{R} + \frac{26{\cdot}4\,K\,N\,\tau^2}{R} \quad \ldots\ldots \quad (1\text{A})$$

and

$$\lambda g = \frac{0{\cdot}685\,R\,W}{N^2\,\tau^2} \quad \ldots\ldots\ldots \quad (2\text{A})$$

from which the following equation is derived—

$$\text{T.W.C.} = \frac{26{\cdot}4\,K\,W}{N\,\tau} + \frac{26{\cdot}4\,K\,N\,\tau^2}{R} \quad \ldots\ldots \quad (3)$$

In (3), the values for K, W, N and R would for any case be given. The problem consists in determining the value for τ which will give minimum cost (T.W.C.). For this purpose we set the first differential of the right-hand member of (3) equal to zero.

$$-\frac{26{\cdot}4\,K\,W}{N\,\tau^2} + \frac{52{\cdot}8\,K\,N\,\tau}{R} = 0$$

$$\frac{2\,N\,\tau^3}{R} = \frac{W}{N}$$

$$\tau = 0{\cdot}795\,\sqrt[3]{\frac{W\,R}{N^2}} \quad \ldots\ldots\ldots \quad (4)$$

Formula (4) gives us the pitch, and hence the diameter, corresponding to the cheapest design, on the assumption of $\phi = 0{\cdot}0010$. It may or may not be a suitable design in other respects, but the point now requiring emphasis is that this will sometimes lead to a low, and some-

Mr. Hobart. times to a high peripheral speed. Letting S = peripheral speed in metres per second, we have the relation—

$$S = \frac{\pi D R}{60 \times 100}$$
$$= 0{\cdot}000525\, D R$$
$$= 0{\cdot}0200\, N \tau$$
$$= 0{\cdot}0159 \sqrt[3]{W R N} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

Those periodicities, speeds and outputs which combine to give us a high peripheral speed when derived by formula (5), are the conditions attending the specifically cheapest design, *i.e.*, the design for a maximum "specific output." Formula (5) shows us that high speed, high periodicity and large output conduce to this end.

Applying these principles to the design of a 75 H.P. 630 r.p.m. (synchronous speed) 42 cycles per second, 380 volt, 8-pole, three-phase squirrel-cage induction motor, we have—

$$W = 75 \times 746 = 56{,}000$$
$$R = 630$$
$$N = 42$$
$$S = 0{\cdot}0159 \sqrt[3]{56{,}000 \times 620 \times 42}$$
$$= 0{\cdot}0159 \sqrt[3]{1{,}480{,}000{,}000}$$
$$= 0{\cdot}0159 \times 1{,}140$$
$$= 18{\cdot}1 \text{ metres per second.}$$

For this design the other dimensions at once follow from the above formulæ :—

Peripheral Speed in Metres per Sec.	(S)	= 18·1
Polar Pitch at Air-gap	(τ)	= 21·6
Rotor Diameter	(D)	= 55·0
Gross Core Length	(λg)	= 29·4

For a squirrel-cage type, the Total Works Cost, in shillings, will be—

$$\text{T.W.C.} = 0{\cdot}6 \times 55{\cdot}0 \times (29{\cdot}4 + 0{\cdot}7 \times 21{\cdot}6)$$
$$= 0{\cdot}6 \times 55{\cdot}0 \times 44{\cdot}5$$
$$= 1{,}470 \text{ shillings.}$$

Dr. Drysdale was of opinion that it would have been interesting to have results for smaller sizes, and I should also like to see similar investigations worked out for, say, half the capacity that I took, *i.e.* for 75 H.P. and again for 37·5 H.P.; but that would involve a good deal of work, though it would make the conclusions still more interesting. Dr. Drysdale criticised my use of L, the over-all length of winding, instead of λg, the core-length. I have used L, the length over the winding, without any special theoretical justification, and simply because one cannot escape from the fact that the product of the

diameter of the rotor and the length over the winding, multiplied by a constant, gives the total average effective cost of the machine, and that this is fairly true for a range of from, say, 5 H.P. to 500 H.P. I have not carried my investigations any further, but 1 : 100 is an enormous range. No such agreement could be found by using λg, the core-length, instead of L, the length over the windings. I am not especially surprised that Dr. Drysdale found a pretty good agreement over the limited range of 10 H.P. to 30 H.P., because it is quite possible for so limited a range as 1 : 3. Mr. Hobart.

I have, by my methods of estimating the total works cost, analysed Dr. Drysdale's table of prices paid by the Northampton Institute for dynamo-electric machinery, and I find that the manufacturers have, on the average, made 75 per cent. profit from that Institution, on the sales on continuous-current machinery to it, and 83 per cent. profit on the induction motor sales.

Dr. Drysdale is, in my opinion, quite right in advocating the restriction of the use of induction motors to constant speed, resorting to mechanical means for obtaining any necessary variations in the speed of the driven apparatus. The induction motor is inherently a constant-speed motor, and all known electrical means of obtaining variable speed from it are very unsatisfactory. The present low efficiency of all mechanical variable-speed gears constitutes, however, a strong argument in favour of the use of the continuous-current motor whenever variable speed is required.

Mr. Meyer referred to a cost formula which employs $D^{1 \cdot 8} \times$ Length. I am of opinion that the Length he uses in his formula is probably the Core Length, and that is more of the nature of the output formula—$D^2 \times$ Length—which is so freely used, and which gives a perfectly true criterion of the output that you can get from a given core provided commutation considerations need not be taken into account. In induction motors it is very closely true through a wide range of sizes, but you cannot take $D^2 \times$ Length as the criterion of the possible output from a given core unless you disregard the commutating requirements, although from a heating standpoint it would be all right.

Mr. Meyer is of opinion that it is useless to consider extreme cases. It is precisely by the consideration of extremes that the true laws useful for intermediate cases become apparent. Mr. Meyer shows by an example that by my formula, a certain 12-pole machine would, when re-wound for 6-poles, cost 43 per cent. more, and maintains that in reality the 6-pole machine would be the cheaper. I disagree with him. In the case he cites, the 6-pole machine has 43 per cent. greater length over windings, and a 20 per cent. greater length over all. The mean length of a turn is 100 cms. for the 6-pole, and 60 cms. for the 12-pole design. Each has the same number of turns. Hence there is 66 per cent. more copper in the 6-pole design. Then again, to avoid too high magnetic saturation, the radial depth of iron should be greater in the 6-pole design, and the total weight of laminations might easily be 50 per cent. greater in the 6-pole design. As for Mr. Meyer's contention that the labour item is greater in the 12-pole design, I would reply that the reverse would generally be the case, since the less the

Mr. Hobart. arc over which the end connections have to be laid, the lower is the labour cost for winding. This is especially the case with the type of winding employed in Mr. Meyer's motors. The coils are first wound in formers, and are then temporarily disarranged and manipulated by hand through a narrow slot opening, and afterwards rearranged in as orderly a manner as practicable. The confusion is evidently much less when only a small pole arc is at any one time the scene of such an operation. In other words, the greater the pitch, the greater must be the percentage of the total number of coils which at one time during the progress of winding are in a state of simultaneous disarrangement.

The interesting curves which Mr. Meyer has contributed, and which are based on the actual results obtained by the British Thomson-Houston Co., afford very valuable confirmation of my own views. It is merely tendencies which I aim to demonstrate in my paper. Thus I thought it important to emphasise the great difference in cost between motors with squirrel-cage rotors and with wound rotors. Mr. Meyer's average value for the difference is 15 per cent. as against my 25 per cent., and he brings out the further interesting point that in his firm's motors it is a function of the rotor's diameter. All of Mr. Meyer's curves confirm the assertions embodied in my four general conclusions, except that some of his firm's lower speed continuous-current motors are cheaper than the corresponding induction motors. While this is partly in conflict with conclusion 1, it serves to strengthen the other three conclusions, and is, in fact, the state of affairs which I started out to demonstrate, but from which I was forced to depart, owing to the average evidence of several firms' motors.

Then, again, had it been practicable for me to take 63 cycles down to the lowest speed, I should have had such very high numbers of poles and consequently also such abnormal diameters that my cost curve for induction motors would have intersected the cost curve for the continuous-current motors at a point somewhere between 300 and 400 r.p.m., thus agreeing with Mr. Meyer's experience with 50-cycle motors of 45 H.P. capacity.

Mr. Meyer repeats the familiar assertion that there are no insuperable difficulties in the design of high-speed continuous-current machines. Why then does the firm to which Mr. Meyer is attached, now at the end of many years of experimenting still restrict its statement of work accomplished in this line, to the rather modest reference to a dynamo of the small capacity of 300 k.w. at 1,800 r.p.m.? The production of continuous-current dynamos of this capacity and speed does not solve the problem. Alternating-current generators in capacities up to *ten times* as great as that are now running, and at speeds in the neighbourhood of 1,000 r.p.m. Such an accomplishment has not been remotely approached with continuous-current dynamos, nor does its accomplishment, however much desired, and despite rumours, appear at all imminent to those acquainted with the difficulties of the problem.

It is a satisfaction to note that the experience of the company with which Mr. Stoney is associated, is, so far as relates to high-speed dynamos, now finally soon to be imparted in the form of a contribution

to the Proceedings of the Institution. Mr. Stoney, referring to this subject, speaks of having accomplished good results in getting high-speed commutating dynamos by means of compensating windings. It is quite true that this has been done in machines of moderate capacity, but it has led to a considerable increase in the labour cost of the machines, and they are not yet in common use, so that one cannot quite satisfy one's self that they are in all respects serviceable under rigorous conditions. It is interesting to hear that Mr. Stoney has designed high-speed alternators which work out far better than designs for slow speed. That is absolutely in accordance with my views. In alternating-current generators as well as in induction motors, the higher the speed the better; but my contention is that just the reverse is the case with continuous-current machinery—there the lower the speed the better. Mr. Hobart

I am in complete agreement with Mr. Williamson as to the inferiority of the induction motor for a large class of work, such as in driving machinery of many classes. My paper demonstrates that the induction motor's superiority shows up at high speeds, and we have the weight of Mr. Williamson's extensive appearance in support of the opinion that for motor-driven machinery, the speeds must be moderate. Hence it follows that the continuous-current motor is most suitable for such work, particularly as it is admirably adapted to variable-speed work, whereas the induction motor is essentially a constant-speed motor.

Mr. Williamson's criticism that my low-speed continuous-current designs are unnecessarily expensive, is to a certain extent true. I entered upon this investigation on the basis of a preliminary estimate that the continuous motor would, at low speeds, show up to great advantage as regards both quality and cost, and I was of opinion that I could, at low speeds, show far better quality and still have lower cost. However, the cost analysis was more in favour of the induction motor than had appeared from the preliminary estimate. By a readjustment I should merely have shown a low-speed continuous-current motor of lower cost than the induction motor, but not so greatly surpassing it in quality. The ultimate conclusions would not have been affected.

Mr. McLeod's analysis of the effect of the periodicity in continuous-current as well as in alternating-current machinery, appears to throw the matter in a new and instructive light. The 4-pole continuous-current motor for 1,224 revolutions per minute is, as he points out, rated rather high. This may be seen from Table I., from which it is seen that reactance voltage, armature strength, current density, and watts per square decimeter of radiating surface of armature and field, are all higher than for the design for the next lower speed. It seems to me right that I should have worked out the design nearer the limit, as otherwise I should have laid myself open to the criticism of having made the highest speed continuous-current machinery unnecessarily expensive, which would have favoured my argument. Thus while Mr. Williamson criticises my lowest speed continuous-current designs as being needlessly expensive, Mr. McLeod finds my highest speed continuous-current design overrated and hence too low in price.

Mr. Hobart. My arguments in support of my conclusions are strengthened by accepting these two criticisms.

In reply to Mr. MacLaren I would say that my $D \times (\lambda g + 0{\cdot}7\tau)$ method for obtaining the total works cost is not based on any theory, but is merely an accidental discovery which I made while studying the longer method applied in Tables III. and IV. I was at the time studying a group of 100 k.w. designs for speeds ranging from 200 to 800 revolutions per minute.* I derived their costs by the longer method, and accidentally noticed the close conformance of these costs to proportionality with the product of armature diameter and length over end connections. This led me to apply the method to a large number of designs of many different manufacturers, and I found the agreement excellent. From Tables III. and IV. it is evident that the agreement between the two methods is within 12 per cent. for ten out of the eleven cases compared. It breaks down in the extreme case of the 68 r.p.m. induction motor. It would be very interesting to have cost comparisons based on the machines of the firm with which Mr. MacLaren is associated. My own experience has been that there is no point on which firms are more at a loss than in this important question of the estimation of the total works cost, and the confusion might be said to be more or less in proportion to the size of the concern. Some firms work backwards from the market price in making up the total works cost of a machine. The resultant of all these influences is that the so-called total works cost is proportional to

$$D \times (\lambda g + 0{\cdot}7\tau).$$

Mr. Ussing points to an additional influence affecting the total works cost, namely the size and quality of a shop's equipment of machine tools. If Mr. Ussing would prepare the additional curves to which he refers, further interesting comparisons could be made.

Dr. Hess mentions the effect which the voltage would have upon conclusions of this sort. He has found the induction motor to have less advantage in small than in larger sizes, the ratio falling to $\frac{K_c}{K_i} = 1{\cdot}3$ at 1 H.P. This confirms Mr. Meyer's criticism. The argument would have become impracticably complex had I taken other than mean values. My mean ratio of 1·5 is in good agreement with the average of Dr. Hess's limiting values of 1·3 and 1·7. Dr. Hess's suggestion of the bearing of the matter upon the question of railway motors is interesting, for while all the new single-phase motors are more expensive and less efficient than the continuous-current motor, and have poor commutation, the three-phase railway motor, according to Dr. Hess's comparison, is not only much cheaper than the continuous-current equivalent, but it has 2·5 per cent. higher efficiency, and the further advantage of no commutator. This would give it a great advantage as to cost, and an advantage of from 5 to 7 per cent. as to efficiency, when compared with the single-phase motor. It is a great pity that all these

* "Der Einfluss der Tourenzahl auf den Entwurf von Gleichstrommaschinen," *E. T. Z.*, 1903, p. 821.

advantages must be sacrificed to the difficulties attending the additional trolley. Mr. Hobart.

Mr. Esson states that it is not generally recognised that his "output coefficient" ϕ applies to induction motors just as to continuous-current motors. I would say that while I find ϕ of very limited utility for continuous-current motors, because it does not take commutation into account, I find it exceedingly useful in induction motor designing. I should like to reassure Mr. Esson as to the practicability of using values of ϕ much higher than those shown by his curve, which, moreover, I have also often found surpassed in Continental practice. Even on small motors I employ values for ϕ lying far above Mr. Esson's curve.

I do not understand Mr. Esson's objection to my "specific output." It has nothing to do with ϕ the "output coefficient." From ϕ we ascertain the output, we may, by suitable design, obtain from a given core. My "specific output" gives the additional important information as to how much output we are obtaining per shilling expended. That information cannot be obtained from ϕ. I find that there is need for both conceptions in commercial designing.

I object to Mr. Scott's interpretation of my paper as a plea for the one or other type of machine. Each type has its field, and there is rarely difficulty in determining the economically correct choice, which is, of course, not necessarily the machine of lowest first cost. As a matter of fact, my own opinion is that there is too strong a tendency to employ the induction motor without due consideration of the ultimate economy and general satisfactoriness. I thought that my paper would make it more clear that for low speeds there is a preponderance of advantages for the continuous-current, and for high speeds for the induction motor. There are many engineering processes inseparably associated with one or the other of these two ranges of speed.

The PRESIDENT: I am sure, gentlemen, we all thank Mr. Hobart very much, both for the paper he has given us and for his reply. On each occasion that Mr. Hobart appears at this table to read a paper, an interesting discussion generally follows, and I think that is what we all wish. I therefore move that our best thanks be given to him. The President.

The vote was carried by acclamation.

The following paper was then taken as read :—

THE RAILWAY ELECTRIFICATION PROBLEM AND ITS PROBABLE COST FOR ENGLAND AND WALES.

By F. F. BENNETT, M.I.E.E.

The opinion held by the large majority of electrical engineers on Railway Electrification is, that for suburban traffic only is it justified. It has been suggested that the electrification of main or trunk lines might result in a loss to the undertakers, as the load-factor at the power-

station would be a very poor one owing to the infrequent headway of traffic; but I shall endeavour to show otherwise. On the other hand, the suburban traffic existing in thickly populated areas calls for a more frequent headway and a greater acceleration of speed. This is not only desirable, but is quickly becoming a necessity, if the suburban railway system is to hold its own with municipal tramway competition; and it can be best attained by electrical methods.

The contention relative to main-line electrification is true if the separate railway companies only considered their own systems, and made electric power provision to meet each individual section of their own lines. If on fifty miles of railway, no matter where located, one power-station were placed in the centre to work that section only, it stands to reason that the expenditure for electrification would not be justified. But, if the plant were competent to work the said section twenty-five miles north and the same distance south of the centre of power, it would also be competent to work all the network of lines within a radius of 25 miles, including even those belonging to other companies. The results obtained under these circumstances would be very different to the case if one section only were worked; it would be found that the load-factor would not only be a good one, but a very satisfactory and profitable one, as I shall endeavour to show in this paper.

Assuming that the railway companies were each to act independently of each other on the question of electrification, as is their inclination at the present time, what would this mean? In 1901 there were 15,308 miles of railway open in England and Wales; consequently, if the companies provided one power-station to work every 50 miles of their systems, there would be required $\frac{15{,}308}{50} = 306$ power-stations for England and Wales. Each company would probably have a separate technical adviser, therefore many and various systems of electric traction would obtain, making it impossible to have in the future a free and easy interchange of traffic, and chaos would reign supreme.

Now assuming that the country could be divided into areas of 900 square miles, and a central power-station were placed in the centre of each area to supply power to all railways, irrespective of whether they are separate companies or not, within such area. With the object of organising a uniform electrical system common to all companies, I would recommend the formation of a central directing Board consisting of members appointed by the railway companies, one representative for every 500 miles of railway or part thereof. After a period of investigation, this Board could finally select and adopt the system of electrification which they deemed to be the best one to be common to all the companies alike.

England and Wales contain 58,370 square miles; if we average the area required for each power-station at 900 square miles (30×30), the total number of power centres required would be $\frac{58{,}370}{900} =$ say 65. This need not mean that every centre of power should be distributed over an area of 900 square miles, but that it can be safely taken that 900

square miles would be a good mean or average to take. In some centres such as Manchester, Liverpool, and Birmingham, a smaller area might be deemed necessary for one power centre ; but on the other hand, there are many thinly populated parts of Wales, Cornwall, Norfolk, Cumberland, etc., etc., where a larger area would not be considered too much for one power centre. Each railway company could subscribe towards the capital cost of erecting the power centres and sub-stations, in the direct proportion or ratio of their respective train mileage recorded in the complete previous year's working. If the system ultimately adopted should be one of polyphase generation, serving direct current to the trains through sub-stations, I would advocate one such sub-station to every 36 square miles, making a total of 25 distributing stations for each power centre.

The Companies could provide their own equipment such as rolling stock, feeders high and low tension, third rail or trolley wires, in fact all the plant necessary outside the power-stations and sub-stations. The current taken by each Company for their purposes could be measured by meter, and the payments due from each individual Company could be ascertained and adjusted by the Railway Clearing House. There can be no question of such a scheme working in a satisfactory manner, and it would be a fair and an equitable arrangement.

I purpose first of all to estimate the cost of electrification under these conditions of the plant necessary to equip the present railways of England and Wales, approximating the amount of annual expenditure, while taking the revenue shown by the Board of Trade Returns for the year 1901. Afterwards to take the probable minimum revenue obtaining, if a reduction of passenger and merchandise rates were made to one-half of those obtaining to-day. In this latter estimate allowance must be taken for an increased acceleration in speed of trains, and a necessarily more frequent headway. If the 65th part of the total train-working expenses and the total revenue of the English and Welsh railways is taken as a basis as the mean obtaining for an area of 900 square miles, a fairly accurate estimate of cost of working can be ascertained.

To discover the total power required for working one section of 900 square miles, it is necessary to calculate the mean weight of each train along with the mean speed. In order to obtain the former, I have made inquiries from several reliable authorities, with the result that 200 tons per passenger train, and 350 tons per goods and mineral train, are safe figures to take. For the former I have based the mean speed upon the time taken by 34 long-distance trains and 15 short-distance trains, taking Manchester as a centre, in accordance to the following tables. This I consider to be a fair average speed by passenger trains in England and Wales. The short-distance trains are taken to be within a 15-mile radius of Manchester at an average distance of 7½ miles. The long-distance trains are taken to be without the 15-mile radius, at an average distance of 68 miles.

There is no certain information to be ascertained as to the mean speed of goods and mineral trains, and for the purposes of this paper I have taken this speed to be 15 miles an hour; with this traffic very con-

siderable delays occur, such as shunting at stations to drop and take up waggons, running into sidings to clear for passenger trains, etc.

PASSENGER TRAFFIC.

TABLE SHOWING THE TIMES OCCUPIED BY THE FIRST FIVE TRAINS EVERY DAY IN RUNNING TO THE FOLLOWING STATIONS FROM MANCHESTER. SHORT DISTANCE.

MANCHESTER to	Number of Miles.	1	2	3	4	5	Average Time.
		Minutes	Minutes	Minutes	Minutes	Minutes	Minutes
Alderley Edge	13	36	25	40	37	32	34
Bolton	11	16	30	16	27	30	24
Bury	9	31	30	1·04	31	30	37
Cheadle ...	8	30	28	26	31	27	28½
Crumpsall ...	2	8	8	8	8	8	8
Eccles	4	15	16	11	16	18	15
Guide Bridge	5	17	19	17	17	17	17
Heaton Norris	5	17	18	18	18	17	18
Lymm	13	38	42	27	33	41	36
Middleton ...	6	29	18	20	20	20	21½
Mobberley ...	12	36	35	30	37	33	34
New Mills ...	14	34	1·0	41	26	29	38
Pendlebury ...	4	13	13	13	13	13	13
Reddish ...	4	13	14	13	8	13	12
Prestwich ...	4	16	16	16	16	16	16
	114	5h. 49m.	6h. 12m	6 hrs.	5h. 38m.	5h. 44m.	5h. 52m.

Five hours 52 minutes are thus taken to cover a distance of 114 miles. This is equal to a speed of 19·45 miles per hour.

Owing to the more frequent headway of service on suburban lines there is not much difference in the number of train-miles run per annum by suburban trains and main line trains, consequently the mean number of miles between the two services would be a fair indication of the mean speed of trains throughout England and Wales. I therefore take $\frac{28\cdot52 + 19\cdot45}{2}$ = say 24 miles as the mean speed for the purposes of my calculations.

In the Blue Book published by the Board of Trade on Railway Returns for England and Wales for the year 1901, we find the following figures given:—

Passenger train-miles	185,852,615
Miles of railway open...	15,308
Passengers carried	1,021,178,850
Total receipts from passengers	£39,608,759
Number of engines (passenger and goods)...	18,511
Number of coaches	41,431

PASSENGER TRAFFIC.

TABLE SHOWING THE TIMES OCCUPIED BY THE FIRST FIVE TRAINS EVERY DAY IN RUNNING TO THE FOLLOWING STATIONS FROM MANCHESTER. LONG DISTANCE.

MANCHESTER to	Number of Miles.	1	2	3	4	5	Average Time.
		Hrs. m.	Hrs. m.	Hrs. m.	Hrs. m.	Hrs. m.	Hrs. m.
Abergele ...	74	2.34	2.53	2.36	2.0	2.32	2.32
Aberystwith ...	140	5.50	6.0	6.25	—	—	6.05
Accrington ...	23	1.15	1.05	1.01	0.54	1.22	1.07
Ashbourne ...	48	2.14	2.05	2.10	2.10	2.55	2.19
Bacup ...	22	1.32	1.17	1.15	1.11	1.11	1.18
Bakewell ...	38	1.21	1.33	1.42	1.55	1.22	1.35
Barnsley ...	36	1.32	1.50	1.27	1.14	2.02	1.37
Barrow ...	87	4.0	3.05	3.25	3.27	3.05	3.24
Batley ...	35	1.19	1.40	1.10	1.19	1.17	1.21
Birmingham	83	4.0	3.35	2.50	2.20	2.20	3.03
Blackburn ...	24	1.08	1.23	1.15	1.16	1.0	1.12
Blackpool ...	49	2.0	1.45	2.05	1.22	1.43	1.51
Bradford ...	40	2.02	2.06	1.16	1.21	1.22	1.37
Bristol ...	191	5.0	4.48	4.52	6.15	5.30	5.17
Carlisle ...	121	4.55	3.50	3.08	3.40	3.58	3.54
Chesterfield ...	58	2.30	2.10	2.21	2.08	2.10	2.16
Colne ...	34	2.18	1.52	1.44	1.26	1.53	1.51
Dewsbury ...	34	1.24	1.35	1.05	1.13	1.18	1.17
Doncaster ...	52	2.20	1.48	1.56	1.45	1.58	1.57
Gainsborough	74	2.33	2.31	2.18	2.33	2.24	2.28
Glasgow ...	222	5.55	6.35	5.28	6.51	5.15	6.1
Hayfield ...	16	1.10	0.51	1.07	0.50	1.04	1.1
Hindley ...	19	0.34	0.48	0.48	0.46	0.52	0.46
Keswick ...	121	2.21	4.20	4.50	3.55	—	3.30
Liverpool ...	34	0.40	1.32	0.45	0.45	0.40	0.52
London ...	183	4.55	3.50	4.50	3.45	4.45	4.25
Macclesfield	17	0.45	0.53	0.29	0.51	0.30	0.42
Newcastle ...	143	4.30	4.18	3.48	4.18	4.22	4.15
Northwich ...	21	0.58	0.56	0.50	0.57	0.59	0.56
Oswestry ...	66	2.27	2.30	3.10	2.37	2.55	2.48
Peterborough	127	3.31	3.39	3.42	3.32	3.38	3.37
Runcorn ...	28	1.38	2.40	2.40	1.57	1.22	2.03
St. Helens ...	21	0.50	1.20	1.33	1.53	1.17	1.24
Sheffield ...	41	1.18	1.10	0.58	1.05	1.12	1.08
	2,322	83.27	84.05	80.59	73.35	70.16	81.29

Eighty-one hours and 29 minutes are thus taken to cover a distance of 2,322 miles. This is equal to a speed of 28·52 miles per hour.

From these figures it is possible to make the following deductions: 900 square miles being 1-65th of the total area of England and Wales, the mean passenger traffic obtaining on that area can be arrived at by using the figure 65 as a common divisor.

The result would be thus divided up :—

Passenger train-miles	2,859,271
Number of passengers carried	15,710,443
Receipts from passengers	£609,365
Number of engines (half)	142
Number of coaches	637
Miles of railway	235

We can further deduce from these figures that there are :—

Passenger train-miles per day	7,835
Passenger train-miles per hour (18 hours per day)	436
Number of passengers per day	43,042
Number of passengers per hour (18 hours per day), say	2,400
Receipts per day	£1,670
Receipts per hour	£93
Receipts per train-mile	4s. 4d.
Receipts per passenger	9·3d.

The result of careful inquiries has elicited that the mean fare per passenger-mile can be estimated at one penny, that being the amount of the third-class fare. The excursion fares are much lower, but are counterbalanced by the first and second class fares, which are higher. If the receipts are one penny per passenger train-mile, and the train-mile receipts are 4s. 4d., the mean number of passengers per train must be 52, and the mean distance travelled by each passenger is 9·3 miles. The main-line and suburban trains are made up of ten coaches, having a mean carrying capacity for 500 passengers; the passenger load-factor is therefore only 10 per cent.

The number of trains required to be actually running—that is to say consuming power—on each 900 square-mile section would be the number of train-miles per hour, 436, divided by the mean speed of each train, 24, viz., 18 trains. I have therefore to estimate for 18 trains, each weighing 200 tons, travelling at a speed of 24 miles per hour. In Mr. W. Langdon's paper read before the Institution of Electrical Engineers on November 29, 1900, he recommends the following formula :—

Tractive effort per ton $= 3 + \frac{V^2}{250}$, where V = speed in miles per hour.

$$\text{H.P.} = \frac{\text{tractive effort lbs.} \times \text{miles per hour.}}{375}$$

The power necessary for 18 trains, each of 200 tons, and making a speed of 24 miles per hour, according to this formula would be :—

$$3 + \frac{24^2}{250} = 5 \cdot 3 \text{ tractive effort per ton.}$$

$$5 \cdot 3 \times 200 = 1060 \text{ tractive effort per train.}$$

$$\frac{1060 \times 24}{375} = 68 \text{ mechanical H.P.}$$

Assuming the total losses to be 100 per cent., which is rather an extravagant figure to take, we have a total power required for 18 trains of $68 \times 2 \times 18 = 2,448$ mechanical H.P. In addition to this, allowance must be made for extraneous power, such as for shunting empty carriages, transit of empty carriage trains, transit of light engines, etc. If 50 per cent. is added for this, I think that it will leave a margin of safety. The total power would therefore be :—

3,672 M.H.P.
$3,672 \times 365 \times 18 = 24,125,040$ M.H.P. hours per annum.
2,739 kilowatts.
$2,739 \times 365 \times 18 = 17,995,230$ kilowatt-hours per annum.

Goods, Minerals, Cattle, and Miscellaneous Traffic.

The Board of Trade Returns for 1901 give the following statistics :—

Goods train-miles	146,520,704
Weight of goods and minerals in tons ...	351,116,884
Receipts	£44,894,936
Number of engines (passenger and goods)	18,511
Number of waggons	547,680

From these figures the following deductions can be made for our 900 square-mile area, by making 65 the common divisor :—

Goods train-miles	2,254,500
Number of tons carried	5,401,798
Receipts	£690,691
Number of engines (half)	142
Number of waggons	8,426
Miles of railway	236

We can further deduce from these figures :—

Goods train-miles per day	6,176
Goods train-miles per hour	256
Receipts per day	£1,892
Receipts per hour (24 hours)...	£79
Receipts per train-mile	6s. 3d.
Receipts per ton-mile...	¾d.

It is impossible to obtain authentic figures as to the actual mean revenue per ton-mile, as no record is kept in any of the Board of Trade or

the Railway Clearing House archives. The rates for all classes of goods and minerals are of a very variable nature. Minerals, for instance, are carried at an average rate of about one halfpenny per ton-mile, whilst eggs are carried at about sixpence per ton-mile. The weight of the minerals, however, forms two-thirds of the whole. After making numerous inquiries from all sorts and conditions of railway people, I have come to the conclusion that three farthings per ton-mile would not be far out in expressing the mean revenue obtaining for all classes of goods and minerals. If 6s. 3d. is the amount of the receipts representing a train-mile, and ¾d. the receipts per ton-mile, the number of tons carried by each train must be 100. The revenue per hour being £79, the number of ton-miles would be $\frac{£79}{\frac{3}{4}d.} = 25{,}280$.

The next point to arrive at is the mean speed of goods and mineral trains. Railway expert opinion being again resorted to, I found that mineral trains from the Midlands to the south and from the north to south made a good average speed of 25 miles per hour; but, on the other hand, there were sad delays in connection with the ordinary goods or mixed trains, and their progress was very slow. The stopping at wayside stations to drop and to pick up waggons, and to clear the way for passenger trains, greatly retarded their speed. The outcome of my investigations was that it would not be safe to allow a mean speed of more than 15 miles an hour.

The number of trains to work this traffic on the 900 square-mile section would therefore be $\frac{25{,}280}{15 \times 100} = 16{\cdot}86$, say 17 trains. Where 25,280 represents ton-miles and 15×100 represents miles per hour × tons per train.

The gross weight of the train I put as follows:—

Goods and minerals	100 tons.
Waggons to carry same	100 "
Locomotive and brake vans...	100 "
Empty waggons on transit	50 "
The total weight would be ...	350 tons.

The power necessary for 17 trains, each of a gross weight of 350 tons, with a mean speed of 15 miles, would be:—

$$\text{Tractive effort per ton} = 3 + \frac{15^2}{250} = 3{\cdot}9 \text{ lbs.}$$

$$3{\cdot}9 \times 350 = 1{,}365 \text{ tractive effort per train.}$$

$$\frac{1{,}365 \times 15}{375} = 54{\cdot}6, \text{ say } 55 \text{ mechanical H.P.}$$

Assuming the total losses between the power centre and the train wheels to be 100 per cent., the total power required would be $55 \times 17 \times 2 = 1{,}870$ M.H.P. The extraneous power absorbed in goods and mineral shunting at the various depôts and at wayside stations would greatly exceed the extraneous power required for passenger service, therefore I consider an additional 100 per cent.

none too much. $1,870 \times 2 = 3,740$ M.H.P. would be the total required for the locomotion and shunting of 17 trains.

$3,740 \times 24 \times 365 = 32,762,400$ H.P. hours per annum.
Converted into electrical (3,470 H.P. = 2,790 kilowatts).
$2,790 \times 24 \times 365 = 24,440,400$ kilowatt-hours per annum.

The total for both passengers and goods is 42,435,630 kilowatt-hours per annum. The power plant required for this would be one of 5,529 kilowatt capacity, but allowance must be made for duplication. In the paper read by Mr. Langdon he considers 100 per cent. necessary for this, so I have based the following estimate on plant of 11,000 kilowatt capacity.

ESTIMATE OF COST OF POWER-STATION OF 11,000 K.W. CAPACITY.

	£	£
Land and buildings	50,000	
Steam generating plant for 11,000 kilowatts at £20 per kilowatt	220,000	
		270,000
Sub-Stations.		
25 stations, each of 1,000 kilowatt capacity, land and buildings	50,000	
25 converters, each of 1,000 kilowatt capacity at £7 per kilowatt	175,000	
		225,000
Distribution.		
Cables, including laying, £700 per mile for two tracks, 235 miles...	164,500	
Extra required for sections of the route where four tracks exist, also for termini and sidings: these calculated to be equal to one additional track, or £350 per mile	82,250	
Contact rail and bonding, £700 per mile for two tracks	164,500	
Ditto for termini and sidings and where four tracks exist	82,250	
		493,500
Rolling Stock.		
285 motor carriages and electric locomotives at £3,000	855,000	
Less credit for 285 existing locomotives at £1,500	427,500	
		427,500
Total cost of electrification		£1,416,000

The above estimate being the cost of one section of 900 square miles, the cost of electrification of the whole railways in England and Wales would be £1,416,000 × 65 = £92,040,000, or say £100,000,000.

The question now arises, would the saving in the working expenses justify this enormous expenditure? I shall endeavour to show that it would, but only on well-organised lines similar to those I have suggested.

In the Board of Trade Returns for 1901 the total train-mileage is put at 332,808,431, made up as follows:—

Passenger	185,852,615
Goods and minerals	146,520,704
Mixed	435,112
Total	332,808,431

In the following calculations I base the cost of the goods and mineral traffic and the passenger traffic only. The total cost of locomotive power (including stationary engines) was £16,786,262. The cost of stationary engines as compared to the cost of the locomotive engines could only be infinitesimal, as they are used primarily for electric lighting and pumping purposes, and as the installation of the proposed electric power-stations would render the further existence of these engines unnecessary, I have not taken them into consideration for the purposes of this estimate.

$$\frac{£16{,}786{,}262 \times 240}{332{,}808{,}431} = 12{\cdot}105 \text{ pence per train-mile,}$$

as at present shown by the Board of Trade Returns.

From Mr. W. Langdon's excellent paper beforementioned, I extract the following points and include them in my calculations. I am sure that the care that has been exercised in compiling them proves their accuracy.

Coal	7·11½d. per ton.
Cost of staff at power-station	·0245d. per kilowatt.
Water	·0050d. ,, ,,

Sub-Station.

Staff	·0299d. ,, ,,
Outdoor service	·0041d. ,, ,,
Oil, waste and sundries	·0109d. ,, ,,
Locomotive drivers and assistants ...	2·6500d. per train-mile.
Repairs and renewals of machinery ...	2·0000d. ,, ,
Renewals of cables and contact rail or trolley wire	·2590d. ,,

The total kilowatts required to be generated to meet the working of the whole system for one year would be:—

$$42{,}435{,}630 \times 65 = 2{,}758{,}315{,}950 = 8{\cdot}288 \text{ kilowatts per train-mile.}$$

ESTIMATE OF ANNUAL EXPENDITURE OF WORKING BY ELECTRICITY THE RAILWAY SYSTEM OF ENGLAND AND WALES.

		Cost per Train-mile in Pence.	Cost per Kilowatt in Pence.
Capital outlay, £100,000,000—	£	d.	d.
Interest at 3½ per cent.	3,500,000	2·5273	·3049
Generating stations staff	281,576	·2031	·0245
Coals, 4 lbs. per kilowatt-hour at 7s. 11½d. per ton, 4,930,028 tons	1,961,740	1·4131	·1705
Water, 25 lbs. per kilowatt-hour at 2d. per 1,000 gallons...	57,465	·0415	·0050
Sub-station staff	343,640	·2477	·0299
Outdoor service	47,121	·0339	·0041
Oil, waste and sundries	125,273	·0904	·0109
Total estimated cost of generation and distribution	2,811,815	2·0297	·2449
Locomotive drivers and assistants the same as at present	3,669,955	2·6465	·3193
Repairs and renewal of machinery ...	2,769,777	1·9973	·2409
Renewals of cable and contact rail ...	358,686	·2580	·0311
Locomotive oil, waste and sundries ...	123,334	·0891	·0107
Rates, taxes, office, insurance, etc. ...	692,444	·5000	·0603
Mixed traffic, 435,112 train-miles at 7·5206 per train-mile, the electrical cost ...	13,635	—	—
Total cost of locomotion	7,627,831	5·4909	·6623
Total cost of the whole	13,939,646	10·0479	1·2121

The saving thus effected is £2,846,616, but it should be noted that this amount includes £3,500,000, the 3½ per cent. interest on the new capital necessary for the conversion. The difference in the cost per train-mile is 2·0571d. in favour of electricity, but excluding the interest on new capital the saving is 4·5844d. per train-mile. The paid-up capital, including loans, for 1901 was £986,646,782, and the saving obtaining from electrical working is equal to 0·29 per cent. The percentage on the cost of conversion is 2·85 per cent., in addition to the 3½ per cent. included in the estimate of cost.

Would this extra profit of 0·29 per cent. be a sufficient incentive for the companies to undertake this revolutionary departure? I am inclined to think that it would not, and yet to yield even this small amount of profit it is essential to treat, for purposes of electrification, the railway system as a whole, and in a properly organised way jointly, otherwise I feel pretty confident that the alteration or conversion could only be brought about by incurring a very heavy loss.

The point now to consider is in what way could electrification be introduced to justify not only this large amount of expenditure, but to benefit the shareholders and all classes of the public alike. It has been proved beyond a doubt that where an accelerated and a more frequent service has been given along with a generous reduction in fares, the traffic has increased fourfold. In this country and in Italy I believe this to be the case. If this large increase has been obtained with passengers, is it not likely to obtain also with goods and minerals? My opinion is decidedly in the affirmative.

Now, assume that by gradual steps the railway companies were to reduce the passenger fares to one-half of the mean obtaining to-day, viz., to ½d. per passenger-mile, and the goods and minerals to ¾d. per ton-mile, and to increase the long distance speed to a mean of 50 miles an hour and the short distance speed to 30 miles an hour, while at the same time doubling the train-miles by giving a more frequent service. The alteration would lead to an increase of traffic to at least three-fold if not more. The passenger load-factor at present of only 10 per cent. appears to me to be so ridiculously low that I think with a little differentiation it could be materially improved. It seems absurd to supply a conveyance weighing 200 tons to convey 2½ tons of people about, and that is what it really amounts to. The high peak of the suburban passenger load is when people are going and returning from business, consequently for ten or twelve hours out of the eighteen the trains are running practically empty. Under these conditions one motor coach and perhaps a trailer would amply suffice during these periods of little traffic, instead of the 200-tons trains in use at the present time; therefore, with double the headway and an accelerated speed a far better passenger load-factor could be obtained. An alteration of this nature would solve many problems, the Housing Question being one of them, the congestion in towns would be relieved, people in the poorest of circumstances could live a few miles out and their railway expenditure could be met by the saving in rent, and overcrowding in big towns would become a thing of the past. The alteration in the goods and mineral services would lead to the revival of many industries, besides bringing into being many new ones. It would be a boon of incalculable value to the agricultural interest. No longer would it be possible to send fruit and vegetables from the Continent to large Midland towns at a lower rate than from our own producing counties; nor would it be probable that finished articles of commerce would be sent from New York *viâ* Liverpool to London at a lower rate as from Manchester to London, as the railway freights to London would be less, which is not so at the present time. There can be no doubt that this question of railway freights has a most important and vital bearing on all our industries.

With the view of ascertaining how the result would be likely to work out if this idea were entertained, I have made estimates showing the probable cost of new plant and the cost of running under these circumstances; I have calculated the increased traffic to be threefold under the conditions I have named.

Allocation for 900-mile section :—

Passenger train-miles	5,718,542
Number of passengers carried	47,131,329
Receipts from passengers...	£914,047
Number of engines	142
Number of coaches	873
Miles of railway	235

I deduce the following from these figures :—

Passenger train-miles per day	15,667
Passenger train-miles per hour (18 hours) ...	870
Number of passengers per day...	129,126
Number of passengers per hour	7,174
Receipts per day	£2,505
Receipts per hour...	£139 10s.
Receipts per train-mile	38·4d.
Receipts per passenger	4·65d.

If the receipts are 38·4d. per train-mile at ½d. per mile per passenger, there would be 77 passengers on each train. If we differentiate in the way suggested, and run trains of sufficient capacity during the day calculated to meet the different press of traffic, the mean weight of train might materially be reduced. By the adoption of a train of 150 tons weight with a carrying capacity of 300, instead of a 200-ton train, we should have a passenger load-factor of 26 per cent., which, under the circumstances, I consider none too large. Taking the average of speed to be 40 miles an hour, the number of trains required to serve one area would be $\frac{870}{40}$ = say 22 trains; in fact, owing to the acceleration of speed from 24 miles per hour to 40 miles, only four additional trains are required.

I estimate the power essential to supply this system to be as follows :—

$$3 + \frac{40^2}{250} = 9{\cdot}4 \text{ tractive effort per ton.}$$
$$9{\cdot}4 \times 150 = 1410 \text{ tractive effort per train.}$$
$$\frac{1410 \times 40}{375} = 150 \text{ mechanical horse-power per train.}$$

Allowing for a loss of 100 per cent. between the prime motor and the train-wheels, we have a total power required for 22 trains of $150 \times 2 \times 22 = 6{,}600$ M.H.P. To add 50 per cent. to this for extraneous power required, a total of 9,900 M.H.P. would be reached, this being equivalent to 7,365 kilowatt-hours. $7{,}365 \times 18 \times 365 = 48{,}388{,}050$ killowatt-hours per annum.

We have now to consider the question of goods and minerals. By the reduction of 50 per cent. in the freight, the big towns in the north

would be brought into closer commercial relation with the towns in the south, the interchange of merchandise would be more self-contained, consequently more independent of foreign supplies. It is well known that all sorts and conditions of producers and manufacturers in this country are greatly handicapped in consequence of the inequality and high rates obtaining in railway freights—inequality, inasmuch as the foreigner has a distinct advantage given him by the railway companies in this country over that enjoyed by the Britisher; high rates, inasmuch as the mean freights of the foreign railways are a very little more than one-half of those in vogue in this country.

The reduction in freights suggested would lead to a greater demand for express traffic, and it would, in my opinion, be safe to base the mean speed of trains at 25 miles an hour. The mean nett weight of merchandise carried I increase from 100 tons to 150 tons per train. The merchandise on a 900 square-mile section under these conditions would therefore be :—

Number of tons carried per annum	16,204,394
Receipts...	£1,036,036
Goods train-miles per annum	4,380,000
Goods train-miles per day	12,000
Goods train-miles per hour	500
Number of tons per day	44,395
Number of tons carried per hour	1,850
Receipts per day	£2,838
Receipts per hour	£118
Receipts per ton-mile	$\frac{3}{8}$d.
Receipts per train-mile	4s. $8\frac{1}{4}$d.

The receipts per hour divided by the receipts per ton-mile, $\frac{£118}{\frac{3}{8}d.}$ = 75,520 ton-miles per hour.

The weight of merchandise, 150 tons × 25 speed in miles per hour = 3,750 ton-miles per train per hour $= \frac{75{,}520}{3{,}750} =$ 20 trains required to be actually requiring power.

Gross weight of train :—

Merchandise	150 tons.
Waggons to carry same	150 „
Locomotive and brake vans	100 „
Empty waggons on transit	75 „
Total	475 tons.

Power :—

$$3 + \frac{25^2}{250} = 5{\cdot}5 \text{ tractive effort per ton.}$$

$$5{\cdot}5 \times 475 = 2612 \text{ tractive effort per train.}$$

$$\frac{2612 \times 25}{375} = 174{\cdot}1, \text{ say, } 175 \text{ M.H.P. per train-mile.}$$

Add to this 100 per cent. to cover total losses, and the power required to run 20 trains would be 175 × 2 × 20 = 7,000 M.H.P. per hour. Add 100 per cent. for extraneous power required, such as for shunting, empty waggon trains, light engines, etc., and we have a total of 14,000 M.H.P. to provide for, which is equivalent to 10,444 kilowatt-hours, and 0·069 of a kilowatt per ton-mile. The total required for both passenger and goods traffic is therefore equal to 17,800 kilowatts per hour. To allow for duplication of plant, I consider that the station should be of a capacity of 36,000 kilowatts. The annual demand of power would be for passengers, 48,388,050; for merchandise, 91,489,440; total, 139,877,490 kilowatt-hours. The total for the 65 stations embracing the whole of England and Wales would be 9,092,036,850 kilowatt hours, and 12,187,716,905 M.H.P. hours.

The passenger train-miles for the whole system would be 371,705,230; the merchandise train-miles, 284,700,000. The total is thus 656,405,230 per annum = 13·85 kilowatts per train-mile.

Estimate of Cost of Power-Station 36,000 Kilowatt Capacity.

	£	£
Land and buildings	50,000	
Generating plant at £20 per kilowatt	720,000	
		770,000
Sub-stations (25), 2,000 kilowatts:—		
Land and buildings	50,000	
Converting plant at £7 per kilowatt	350,000	
		400,000
Distribution cables, including laying for two tracks at £700 per mile	164,500	
Extra required for sections of line where four tracks exist, also for termini and sidings—these are calculated as being equal to one additional track, £350 per mile...	82,250	
Contact rail or trolley wire and bonding, £700 per mile for two tracks	164,500	
Ditto for termini, sidings, and where four tracks exist, £350 per mile	82,250	
		493,500
		1,663,500
Rolling stock the same as in other estimate ...		427,500
Total cost		£2,091,000

The total cost of electrification for the whole of England and Wales would therefore be, £2,091,000 × 65 = 135,915,000, say £150,000,000.

Estimate of Annual Cost of Running.

		Cost per Train-mile in Pence.	Cost per Kilowatt in Pence.
Capital outlay, £150,000,000 at 3½ per cent.	£ 5,250,000	1·919	·1385
Power-Station.			
Staff	464,073	·183	·0122
Staff (sub-station)	568,252	·207	·015
Coals, 4 lbs. per kilowatt-hour at 7s. 11½d. per ton, 16,236,780 tons ...	6,460,487	2·362	·1705
Water, 25 lbs. per kilowatt at 2d. per 1,000 gallons	189,417	·069	·005
Out-door service	94,708	·035	·0025
Oil, waste, and sundries	189,417	·069	·005
Total	7,966,354	2·925	·2102
Locomotives.			
Wages to drivers and assistants. As the mean speed has been increased by 60 per cent., the wages per train-mile has been reduced by 40 per cent. in these calculations, viz., to 1·59d. ...	4,348,684	1·590	·1148
Locomotive oil, waste, and sundries ...	189,417	·069	·005
Repairs and renewals of machinery, 2½ per cent. on capital outlay of £150,000,000	3,750,000	1·188	·0857
Office, rents, rates and taxes	1,094,008	·400	·0288
Grand total of expenditure ...	22,598,463	8·091	·5830

The question now arises as to what additional capital would be required to provide the extra accommodation necessary to cope with three times the traffic to that obtaining at the present time. It is a well-known fact that for many years past the railway companies have been spending large sums of money in extending their premises, and have, without doubt, provided accommodation for greatly increased traffic for many years to come. The great bulk of the through stations would require very little additions to their size and accommodation to meet this increase in the traffic, but I see that great congestion would take place at termini and on the main trunk lines, some sections of which would necessarily have to be widened. There would also be some considerable additions to be made to the rolling stock, also in the extension of collecting and delivery vans.

Time will not allow me to enter in full detail into the cost, but, roughly speaking, I think that an additional sum of £150,000,000 would go a long way to cover it. If I am right in this supposition, an increase of capital equal to £300,000,000 would be necessary to cope with the proposed greater train-mileage and the trebled traffic.

The total receipts for 1901 were £90,703,770, and the total working

expenses were £58,349,606, being 64 per cent. of expenditure to receipts. We have ascertained the additional cost of locomotive working, but what would be the additional cost of dealing with the increase of traffic in other departments? A large increase in the subordinate staffs would be imperative, but only in those staffs, as the chief officials would be a standing charge and require no increase. I think that an increased expenditure of 25 per cent. in all other departments except that of locomotion would meet the requirements of the additional traffic. Now deduct the cost of locomotion, £16,786,262, from the total expenditure of £58,349,606, = £41,563,344, add 25 per cent. = £52,954,177, and also add to this the cost of locomotion under the new conditions, £17,348,463, and we obtain the figure £70,302,640, which is therefore the estimated cost of working the whole system under the new conditions.

The gross revenue obtaining would be increased from £90,703,770 to £136,055,655, and the result in the percentage proportion of expenditure to total receipts would be 51·6 per cent. as against 64 per cent., the figure obtaining at the present time.

The proportion of nett receipts to paid-up capital in 1901 was 3·279 per cent; the same proportion under the new proposed conditions would, after increasing the capital by £300,000,000 (viz. to £1,286,646,782), be 5·1 per cent., or an increase in the profits of 1·831 per cent., which would represent an additional profit of £23,558,421 per annum.

If such a revolution as I have suggested were to take place, I do not think that my prognostications would be found to be very wide of the mark. I feel confident that something akin to these results would be realised if the experiment were made, but strict and harmonious organisation between the companies would be absolutely essential.

In a little pamphlet entitled "Should Railways be Nationalised," by Mr. W. Cunningham, much very useful information is given, which undoubtedly justifies that gentleman's contention. He claims that under State management a saving of £30,000,000 would obtain. While not quite sharing this sanguine conclusion, I feel convinced that, either by State control or combination of the companies, a very great economy in expenditure might be looked for. The 3,000 directors could be dispensed with, as also the 2,600 clerks in the Railway Clearing House, and as many more employed in the audit departments of the various companies, these latter being employed to check the accounts between the companies. Unnecessary duplication of staff could be avoided, such as that in Manchester, where six systems compete and each employ a separate staff of officials, all of which work might be well accomplished by one staff. Wasteful rivalry would cease, and trains not in competition with each other could be run more in harmony with the wants of the people. Duplication of stations would not be required. Competition with the Post Office for parcels traffic would cease. Legal expenses could be reduced to a minimum, owing to the joint and harmonious working, which would replace the pulling in opposite directions which many of the companies are doing at the present time.

Duplication of merchandise offices would become unnecessary, and

instead of one merchant having half a dozen collecting vans calling upon him daily at his place of business, one only would suffice. There would be no need to sort out by shunting the foreign waggons to be returned to the respective owning company, but the rolling stock could be made common to all companies, and waggons, after discharging their loads, could again be utilised for traffic to any destination. In fact there is scarcely any limit to the saving that might be effected if amalgamation or State control were possible. A saving equal to £11,446,787 might easily result under such joint and direct management, and this would make the expenditure exactly 43 per cent. of the gross revenue, the result being a profit equal to 6 per cent. on the whole of the capital invested. If the State were to obtain control and absorb the companies at par value, the whole could be paid off in twenty-four years by adopting a sinking fund of 3 per cent. while paying 3 per cent. interest.

In conclusion, I wish to warn the railway companies from continuing in their present policy with regard to electrification. Indiscriminate installations are useless for proving whether electrification is economical. The only way by which electrical working can be made cheaper than the present method, is by adopting one system common for all companies, controlled by one central body like the Railway Clearing House.

There are six or seven railway systems in Manchester: would that centre not be a good one to test the system I advocate? Assuming that Manchester and fifteen miles round were electrically equipped, the experiment could be made by reducing all the passenger fares to one-half within that radius; and if treble traffic resulted, my theory will have been proved to be correct. The next course to be pursued would be to electrify the whole of Lancashire in the same way, reduce the present fares and freights to one-half within the county, and if the expected results are realised, then the whole of England and Wales could be proceeded with.

To show how British internal trade is handicapped by heavy railway rates, the following list will demonstrate the advantages possessed by the foreign producer over the British :—

1. Carriage of a ton of apples, Folkestone to London, £1 4s. 1d.
   Carriage of a ton of apples, California to London, 15s. 8d.
2. Carriage of a ton of British meat, Liverpool to London, £2.
   Carriage of a ton of foreign meat, Liverpool to London, £1 5s.
3. Carriage of a ton of eggs, Galway to London, £4 14s.
   Carriage of a ton of eggs, Denmark to London, £1 4s.
   Carriage of a ton of eggs, Russia to London, £1 2s.
   Carriage of a ton of eggs, Normandy to London, 16s. 8d.
4. Carriage of a ton of plums, apples, and pears Queensborough, (Kent) to London, £1 5s.
   Carriage of a ton of the same from Flushing (Holland), 12s. 6d.
5. Carriage, per ton, of English pianos, Liverpool to London, £3 10s.
   Carriage of above, of foreign, £1 5s.

6. British timber, per ton, Cardiff to Birmingham, 16s. 8d.
   Foreign as above, 8s. 10d.
7. Carriage of nails, wires, tubes, per ton, from Birmingham to London, 10s. 9d.
   Carriage of same from Germany, 4s. 9d.
   Carriage of English spades, per ton, £1 1s. 9d.; of German, 6s. 6d.

In the carriage of iron ore and steel rails, the American railway charge 6s. 3d., where the British charge 29s. 3d.

The PRESIDENT: Mr. Bennett is unable to be present to-night, and I presume you will take his communication as read. The subject Mr. Bennett deals with is one which would be, perhaps, much more ably treated by a railway engineer, as electrical engineers cannot claim to have any wide experience in railway traffic matters. I believe that some railway men are here to-night, and if they will oblige us with their views, we shall be very glad indeed to hear them. I understand Mr. Mordey has a few remarks to make, and, if so, we shall be obliged if he will open the discussion. The President.

Mr. MORDEY: I am sorry, sir, that I myself am not prepared to speak to-night, but my friend Mr. Henry Sayers, who is unfortunately ill, has sent me a contribution to the discussion which he asked me to read. Mr. Mordey.

Mr. H. M. SAYERS (*communicated*): We must all of us recognise that, both for the credit and the material benefit of our profession and industry, no more important task lies before us than the convincing of the railway world and the investing world that the electrification of our railways will be at once a financial success and a great national benefit. Doubtless, Mr. Bennett has attempted to do his part in that work by means of the paper he has put before us to-night. Unfortunately, it appears to me that he has based his whole argument and train of calculations upon such an unsound foundation that it can be expected to carry no conviction whatever, and may even have the unfortunate effect of persuading some that electrical engineers do not understand the elements of the problem. Mr. Sayers.

Mr. Bennett's fundamental error is that of "averaging." He has taken the total railway traffic, receipts, train mileage and other relevant figures, and assumed that if he divides these out equally among a number of equal areas, then he may say that the cost of electrifying such an area, the working costs, the receipts and the profits may be properly taken as representing *pro rata* similar figures for every other area, and therefore for the whole country.

I submit that this average-area method is indefensible and profitless. It has the effect of ignoring entirely some of the facts which form the most difficult problems in the way of general railway electrification. It is precisely in the "thin" area that greatest difficulty is presented, the question of keeping down capital expenditure, while ensuring efficient service and distribution, and maintaining a reasonable load-factor, and this difficulty is quite put out of sight by the "average area" method. The assumption is so far from the facts that to treat

Mr. Sayers. it as even an approximation suggests want of acquaintance with the problems.

Take a railway map of England. Take out of it the following of Mr. Bennett's "areas." Metropolitan, Bristol, South Wales Coal Fields, Birmingham, Hull, Sheffield, Manchester, Liverpool, Leeds and Bradford, Newcastle-on-Tyne, nine out of the sixty-five, and consider how much the output, load-factor, and traffic receipts of the fifty-six would be reduced. Further demonstration is hardly needed to prove that the "average" area of Mr. Bennett'sis a purely imaginary entity. And it by no means follows that the "fat" districts compensate for the "lean." Working one station at a poor load-factor is not in the least compensated for by working another at a good load-factor. One is simply better off without the "lean" district. The cost of distribution is even more hopelessly against the "lean" district for reasons that need not be gone into here.

Mr. Bennett has not only averaged things geographically, but also in respect to time. The whole year's passenger figures are smoothed out over 18 hours of 365 days, and the average load, etc., so arrived at taken as that to be provided for. For goods 24 hours per day is taken. One need not be a railway expert to know that there are not only great differences in railway traffic as between one season and another, as between week-days and Sundays, but also as between hour and hour of each weekday. These traffic "peaks" are what determine the provision for generation and distribution of power, and, of course, the whole of the financial results, and this time-averaging, just as much as the area-averaging, has the effect of greatly reducing Mr. Bennett's figures for capital expenditure, improving his load-factor, and, generally, putting a rosy colour upon his estimates.

A comparatively minor point, yet making for the same result, is his estimate of the power needed for the mean train. A mean speed of 24 miles per hour is taken, and the figures of tractive effort put forward as the basis of the power calculation is merely that needed to keep a train of 200 tons weight in motion at 24 miles per hour on a straight-level track. No allowance for acceleration, nothing for gradients, nothing for curves. The 5·3 lbs. per ton placidly assumed will be doubled on a rising gradient of 1 in 420, even on a straight line. A "side-on" gale will add as much more. Falling gradients far from compensate for rising ones. Just as far from compensating for acceleration expenditure is the drifting to a stopping station. It is difficult to suppose that Mr. Bennett has not seen the diagrams and papers that have taken so large a space in the technical press of late months—demonstrating the large amount of energy called for by quick-stopping and starting; but he makes no sign of knowledge.

On the other side, the estimates are made out on the bases that 50 per cent. of the power generated will be lost in distribution, and that rotary converter sub-stations and continuous-current distribution will be used. The distribution efficiency, *i.e.*, from switchboard to car wheels, may not be much underestimated with the converter system suggested, but by means already in sight better results may be safely expected.

No one, however, can suppose that our general railway electrification is going to be based on rotary converter sub-stations. Something much simpler and more economical in both capital and working expenditure will be necessary, and there are hopeful signs that this will soon be available. I will refrain from further criticism, as the points dealt with are enough. Mr. Sayers.

I want to make it clear that I believe that general railway electrification will come, that it will be an economic and a social success, and make our railways enormously more useful and valuable to the community than they are now. All the more do I think it unfortunate that a paper written on this subject should be based upon unsound premises that will give the impression that electrical engineers have not begun to appreciate the realities of the case, and are therefore unreliable guides.

Mr. Langdon's paper was most valuable. He took a concrete case, and showed how it could be dealt with and what would be the result. It is only by dealing piece by piece with the whole of the extremely varied circumstances and conditions of our English railways, and showing that a consistent, well-thought-out scheme of electrification, with sufficient elasticity to meet variations, and sufficient uniformity to ensure reliable through working, can be applied throughout, that we can hope to convince those who will have to find the very large amount of capital required to carry out the work.

Conviction by example will doubtless prove the most effective, but we will have to get the opportunity of such proof by clear reasoning upon actual facts, not upon smoothed-over averages which correspond to nothing real.

Mr. J. W. Jacomb-Hood: I suppose no one imagines that the great problem is going to be solved in this particular way, and yet I think, without being very severe, we may enjoy a few minutes over it. At any rate, it is a subject for discussion. The suggestion is before us, and it is worth considering a little bit before we leave it altogether. Assuming the financial difficulties are entirely removed—and of course they stand in the way really of anything on such a scale as this—such a grand and attractive scale, one may say, because it is most interesting and attractive as one reads the paper—assuming those difficulties are all removed, it is fair to inquire, as, indeed, Mr. Sayers did—or, at any rate, he suggested it—whether the power that Mr. Bennett proposes, upon which really the whole scheme depends, is anything like sufficient. Really that is the most interesting point in such a grand question as this. Mr. Bennett appears to me to have taken a wrong basis for his figures in assuming that the mechanical H.P. of trains, as it is to-day, on his average area of 900 miles, will be a guide in the future for his scheme of general electrification. It seems to me that, if electrification is justified at all, it will involve more trains and much faster trains, and that therefore the electrical load will be without question larger than the mechanical H.P. involved in to-day's working. That is the first thing. Then again, it seems to me, as it does to Mr. Sayers, that the tractive-effort formula which Mr. Bennett has used makes no allowance for the hundred and one difficulties that are constantly arising. To Mr. Jacomb-Hood.

Mr. Jacomb-Hood. suggest to the world that a tractive effort of 5·3 lbs. per ton is sufficient is evidently a mistake. The formula was put forward by Mr. Langdon, and some severe things were said about it. It is quite evident that a very much larger figure must be put forward for the tractive effort before you can arrive at the H.P. which you must expend on your railway. It is not a question that I have had time to go into, and no doubt many gentlemen here are much more able to speak scientifically on the point; and I have only looked into some of the figures within the last couple of hours. Mr. Langdon, you will remember, suggested the employment of 10,000 k.w. upon a 50-miles line of railway. That is a better guide, one thinks, than this suggestion of a 10,000-k.w. plant for the running of 235 miles of railway. This question of power employed on railways to-day was investigated by my staff, partly for this purpose, and partly for another purpose, only last summer, and we, on the railway that I have the honour of serving, went into the question with some little degree of accuracy, the result being put upon the diagram on the wall.* That shows the service of trains on a day which we regarded as the day of our maximum load on our main line as between London and Southampton. The day was Saturday, the 2nd of August, 1902, which was the Saturday before the Coronation Review. The red lines that you see in the upper part of the diagram indicate, each one by itself, a passenger train, and the green lines indicate goods trains. The speed of each train is to be obtained by the angle with the horizontal, and the gradient, by the profile of the line between the points, is shown at the further end of the diagram. Assuming a fixed average weight, as one is obliged to do, and as, indeed, Mr. Bennett has done, both for passenger trains and for goods trains, taking the speeds upon the diagram and assuming the whole service to be running against a gradient of one in 750 (which, after a good deal of investigation, we thought was a fair average), we arrived at the mechanical work done on our line, and that mechanical work done, calculated minute by minute for the first two hours and afterwards at longer intervals, is indicated by the lower line, giving the millions of foot-lbs. per minute. When you come to look at the generating plant at the power-station, you will see what you would have to provide for such a load as the diagram shows. You will see at the peak, which is between 11 and 12 o'clock, you are expending effort equal to something like 875,000,000 foot-lbs. per minute, and after making very little allowance indeed in turning that into electrical energy, you will see that you must have a generating station of 20,000 kilowatts on an 80-miles line. That hardly bears out Mr. Langdon's figure as sufficient, and therefore probably Mr. Bennett's figure is still less correct. It is pretty evident in fact, I think, to all of us, that Mr. Bennett's figures of power expended are very much on the low side, and must certainly be raised if we are going to arrive at anything like the probable cost of a general electrification scheme such as he suggests. Supposing one takes Mr. Langdon's figure, which I think was at the rate of £10,000 per mile, Mr. Bennett's figure coming out to something under £7,000 per mile, that would at once raise the cost per train-mile by 1¼d.—that is, the cost per train-

* Not reproduced here.

Mr. Jacomb-Hood.

mile immediately goes up for interest on capital outlay by 1⅛d. In the table on page 517 there is an estimate of the annual expenditure on working, and there is then another figure which I venture to think can hardly hold water. He takes coal at 7s. 11½d. per ton. I do not know what the experience of other railways is, but I am perfectly certain that the company I serve will not be able to buy coal for generating plant at anything like 7s. 11½d. In fact, it comes to this—that figure is a very important figure, amounting on Mr. Bennett's showing to 1·41d. per train-mile, and it will have to be raised. I do not think one could put the average price for the country at less than 10s. per ton. If that is so, up goes the cost per train-mile by another ⅜d. That will produce a total per train-mile, according to Mr. Bennett's showing, of something like 11⅝d. Then he compares that cost for electrical working per train-mile with the cost per train-mile that he has deduced from the figures shown in the Board of Trade Return for 1901, the average price per train-mile according to that return being 12·105d. That is with steam, of course, and he compares that cost with a cost per train-mile on electrical working of 10·04d., which I venture to think, for the reasons given above, ought to be at least 11·5d. The Board of Trade Return for 1902 shows a very considerable reduction in the cost of haulage per train-mile, and I think it would be interesting to this meeting to hear what the actual cost of haulage by steam service was in the past half-year. The figures happen to have come to my hands quite recently, and they are very interesting. Of the eleven great companies in the country, running between them nearly two-thirds of the train-mileage of the country, the total cost of haulage only amounts to 11·54d. per train-mile, and of those eleven companies only three are above the average, the rest being slightly below the average; so that, on Mr. Bennett's own showing, the advantage of electrification disappears at once. However, I venture to think that Mr. Bennett has not made the best of his case. First of all, the electrical train mileage will be quite evidently very much larger than is steam train mileage to-day, and although he is taking his figures on the present train mileage, directly he electrifies, his electrification will only be justified by a very large increase of service. Therefore his train mileage will very speedily increase. Of course the train mileage by electric traction will not be the same as that by steam traction, but the former will have a very much larger power-factor than the latter, and so the results may be the same. That shows the absurdity of using the train-mile as a measure of work done by a railway. It is quite evident that the train-mile is really of about as much use as a guide to work done as a lump of chalk is for a measure of capacity or a piece of string for a measure of length. But that is by the way. The latter part of the paper deals, not with the problem of cost, but with the question whether general electrification will secure an increase of profit to the companies. The author wishes to show that increased services will mean increased takings. It is evident that if he carries twice as many people for the same rates, his earnings will increase, and it is also evident that if he carries twice the number of people in order to arrive at the same profit, he may charge half fares, and then similarly any further increase of traffic will mean a

Mr. Jacomb-Hood.

greater profit. But all that is problematical. At the same time we cannot help thinking that there is a possibility of development of traffic when you come to think of the comparative number of rides per head of the whole population in various countries. The rides per head per annum of the population in New York City in the year 1902 amounted to over 400—403, I think it was—whereas the rides per head in Greater London in the same year only amounted to 120. Further than that, the rides per head of population throughout the whole of Great Britain only amounted to just over 40 in the same period. There is a great difference in those figures, and one can only hope that there is a possibility of development in passenger traffic as well as in goods traffic. If there is, it may be that Mr. Bennett's proviso may be justified, and that we shall have a very largely increased traffic as the possibility of carrying traffic is more easily developed.

One is at least a little sorry to see Mr. Bennett giving up the electrical question for a moment in order to have a dig at the railway companies in the latter part of his paper. Really it is not worthy of him. It is hardly the sort of argument to offer to a body of gentlemen such as yourselves, because the comparative figures that he gives in the last part of his paper are so easily explained away and are so evidently not comparable—he is really comparing like with unlike. He suggests the carriage of a ton of apples from Folkestone to London, and he compares that with the carriage of a ton of apples from California to London, nearly the whole of which is water carriage. There he is in fact comparing railway carriage with water carriage. It has never been suggested that railways, who have to pay for their right of way, and to pay very heavily too, can compare with the free right of way that water gives. Then he is comparing rates which are through shipping rates with rates that are local rates. He refers to the charge for carrying a ton of English meat from Liverpool to London—£2, and he thinks that ought to be carried at the same rate as foreign meat going from Liverpool to London—£1 5s.

A Member.

A MEMBER: Why not?

Mr. Jacomb-Hood.

Mr. JACOMB-HOOD: The reason is that if the English meat were offered to the railway companies under the same conditions as the foreign, it would be carried at the same rate. That has been stated over and over again. If the conditions are equal, the rates would be equal; but the conditions are not equal. In one case you have a ton, and in the other you have a shipload, which makes all the difference in the world. There is another case very much like it. He gives the carriage per ton of English pianos from Liverpool to London—£3 10s., and the carriage of foreign pianos from Liverpool to London—£1 5s. The foreign pianos he is speaking of are part of a shipload of goods. They are probably American pianos coming to London and that £1 5s. rate is part of a shipload rate, whereas the English piano rate is for a single piano. Of course, if the English piano maker in Liverpool will only ship his pianos from Liverpool in trainloads, he would get the cheaper rate.

Mr. Morrison.

Mr. G. J. MORRISON: After the somewhat scathing criticism of the paper, I feel a little ashamed to get up and say anything more against

it, so I shall confine myself to one point only. At first sight, the point which I have now to speak upon might appear to be a detail, but I think I will be able to show you in a minute or two that it really goes to the root of the question. Mr. Bennett, in working out this scheme, makes it quite clear that in order to carry the traffic which he proposes to carry, he must increase the speed of his trains. He proposes to increase the speed from a mean speed of about 28 miles per hour to a mean speed of 50 miles per hour; that is to say, by about 70 per cent. Of course that does not mean that a train that is now running at 60 miles per hour would necessarily run at 82 miles per hour, but it does mean that the trains which are now running at a fast rate must have their speed increased. The very interesting time-table, in the form of a diagram, which is in front of us gives me an opportunity of showing exactly what I mean. If my eyes do not deceive me, there is a train which leaves Waterloo a little before eight in the morning, and arrives at Basingstoke about twenty minutes past ten; and there is another train which leaves at nine o'clock in the morning, and arrives at Basingstoke about a quarter past ten; that is to say, it leaves about an hour and a quarter later and arrives a few minutes sooner. If you look at the running time of those two trains, judged by the slope, you will see that when the trains are running they are travelling at about the same speed. But it requires no diagram to tell us that the so-called slow trains are slow because they stop a good deal, not because they run slowly, and therefore if you increase the mean speed you have to increase the maximum speed. I think I shall be borne out by a good many people in saying that many facts point to the conclusion that we have very nearly arrived, if we have not quite arrived, at the maximum speed for trains on English railways. Of course I know very well what has been done in Germany. I know that trains have been run at 200 kilometres per hour and more, over a permanent way of the same general description as that of our English railways, but between the German line and our English lines, as a whole, there are many points of difference. For instance, the particular line on which that high speed was run is a line without any over-bridges, without any curve of a radius less than 2,000 metres, and, I believe, without any junctions. We get none of these conditions on the English lines. If you travel in England, particularly over lines which were made originally as local lines, and where, consequently, quick curves were introduced to save expense, but which have now become important lines, you will feel the curves as you go round them, and you feel a shock when you enter them. That shock might perhaps be got over. It can be done by the introduction of a transition curve, and although it is a very expensive thing to introduce such a curve on an existing line, it can be done. But when you have got that, you still have to run round the curve, and this introduces a difficulty which, at first sight, seems a trifling one, viz., the introduction of sufficient super-elevation of the outer rail. Any one who has seen bicycle races knows very well that where you have great speed and quick curves, if you have a sufficient amount of super-elevation, you run satisfactorily, and it might seem a very easy thing indeed to put a considerable super-elevation on a railway. In England we have

Mr. Morrison.

Mr. Morrison.

been in the habit of putting rather less than is done in other countries. We have arranged the super-elevation as a rule more nearly to suit the mean speed than to suit the maximum speed, but when you come to very great speeds, you have to consider the extreme danger of running at these high speeds, and you have to make the super-elevation good for the quick trains, both because an accident is more likely to happen with them, and because, when an accident does take place, it is more serious. But if you put sufficient super-elevation for these quick speeds, the corners of the carriages will come against the over-bridges, which of course would be a very serious matter. In the case of tunnels it is perhaps not quite so bad, because, although we have a great many curved tunnels near the cities, yet the speed there would naturally be slow. The number of curved tunnels in the open country is very small, and, if you had to reduce speed in them, it would not matter very much; but the number of quick curves in the open country is very great, and if you had to rebuild the whole of the bridges over such curves, to enable the carriages to pass safely with the increased super-elevation, the expense would be very great. Besides that, on these quick curves of a quarter of a mile radius, and sometimes less, or take even a quarter of a mile, with the super-elevation which is wanted for these higher speeds which you are going to have, it would be extremely inconvenient, to say the least of it, to run the slow trains; and with a super-elevation of a foot or eighteen inches it would be not only inconvenient but dangerous even when a high-speed train slowed down, to say nothing of ordinary slow traffic. Therefore, practically, with the present curves you cannot do it. Then you have the junctions. Wherever you have a junction, at least one line must be curved, and in a great many cases both. At a junction you cannot put any super-elevation at all, because the rails will not cross each other unless they are on one plane. Therefore you must run slowly through the junctions. If you have to slow down everywhere, if, that is say, you have to slow down where you have junctions, and if you have to slow down here and there where you have quick curves, you cannot keep up any higher speed than the speeds which we have at present obtained on our present lines. Therefore no system of working the ordinary traffic of this country electrically which involves a material increase in the speed of the quick trains is really worth serious consideration, unless the problem of so altering the existing lines as to make them fit to carry those quick trains is fully dealt with. I know that, in the case of roads and streets, it is very often a cheaper thing to run a road through a block of buildings than to set back the existing building line three or four feet; and so it may very well be that in many cases it would be cheaper to make an entirely independent line for the quick traffic than to try to alter our existing lines of railways, with three, four, five, and six pairs of rails, as they sometimes are—to say nothing of our great goods yards. I will not go into the question of which method of carrying quick traffic is the better; but certainly, as I said before, the question of making our railways suitable for carrying quick trains must be dealt with before you take any credit for carrying a greater amount of traffic through running the trains at a higher speed.

Mr. JAMES HOLDEN (*communicated*): On page 515 of the paper the credit for existing locomotives is given as £1,500 each, equal to £427,500 for the locomotives in one section; but if the proposal to electrify the whole of the railways in England and Wales were carried out, the present locomotives would only have a scrap value attached to them, which I should estimate at about £250 each, a total for the 285 locomotives of £71,250, or a decrease of £356,250 on the figure given in the paper. This item alone would, over the whole of the sixty-five sections, show an increase in the total cost of electrification of £23,156,250. Mr. Holden.

The price of coal for the year 1901 is shown as 7s. 11½d. per ton. The average price, however, for the railways of England and Wales during the year in question was 12s. 1d. per ton, making a difference of over £1,000,000 in the annual expenditure for coal.

With reference to water, a figure of 2d. per thousand gallons is quoted. Even assuming that the whole of the water would be pumped, the figure appears to me to be somewhat low. It should, however, be borne in mind that at many places water has to be purchased from private companies, and from my experience I should estimate the cost at at least 6d. per thousand gallons.

Mr. W. LANGDON (*communicated*): The author will, I hope, pardon me if I dissent from the opinion to which he has given expression in the opening portion of the paper, viz., that only for suburban lines is the electrification of railways justified; and again, that "the electrification of main or trunk lines might result in a loss to the undertakers, as the load-factor of the power-station would be a very poor one, owing to the infrequent headway of traffic." Mr. Langdon.

This is not, in my opinion, the view of electrical engineers, and it is very undesirable that any such expression should go forth to the railway companies or to the public. There is a certain inconsistency in the assumption that the headway of traffic on the trunk lines is infrequent. Why do railway companies continue to increase the number of lines of rails in the neighbourhood of the metropolis and other large railway centres? The traffic of the main arteries will be found to constitute three-fourths of the entire traffic of any large system. Trains are not only infrequent on branch lines, but most branches are absolutely closed for several hours out of the twenty-four. There can be no question that the most lucrative section of a line of railway for electrification is the trunk-line portion. Mr. Bennett surely does not look for the bulk of traffic in a 30-mile square in the branch lines!

Mr. Bennett fixes, for the purpose of his calculations, the average speed of passenger trains at 24 miles and the load at 200 tons, and the speed of goods and mineral trains at 15 miles, with a load of 100 tons. Few railway men will be found to support these figures. It is only omnibus trains that will conform to 24 miles an hour. Goods and mineral trains are delayed *en route* by being shunted at points to make way for more important trains. Worked by electricity, trains so standing would call for no energy. This is one of the points where the economy of electrical propulsion would assert itself. To reduce

Mr. Langdon.

the speed to a common average is not quite proper, for the reason that the higher speed calls for a much larger output of energy per mile. The actual running speed would seldom be so low as 15 miles per hour.

This would increase Mr. Bennett's costs, but he has a large asset in the charge he has adopted from my paper, as that at that time set down, for repairs and renewal of machinery, twopence per train-mile. In my paper, I explained why I had adopted this high rate, and in my reply to the discussion I laid emphasis upon the point. Mr. P. V. McMahon, in his paper, read before the Institution on December 17, 1903, gives the "total costs, including salaries and wages connected with the generating of power, running of locomotives, coal, water, and other stores, material and wages for repairs," at 4·61 pence. Mr. Bennett, as I understand, allows 7·5206 pence. There are a great many economies which might be effected if electricity were the motive power, which the author has in no way noticed.

Acceleration is an important factor where the trains meet with frequent stoppages, but it is not so important a factor on main lines, where the stoppage of trains is much less frequent than on suburban lines.

That passenger traffic would increase under reduced rates and greater facilities is probable, but traffic in goods and minerals is chiefly dependent upon consumption and trade, and that that would be quadrupled, or even *very* largely increased, is open to doubt.

Mr. Bennett has viewed this question from a very broad basis, and it is to be regretted that his deductions are somewhat of a negative character. The nationalisation of our railways or their being merged under one central control would, no doubt, admit of economies; but it is questionable whether either would be to the interest of the public. If Mr. Bennett looks to a combination of this character, or to a common supply between the companies, as the only means by which the electrification of our railways will be effected, I am afraid it will never be accomplished. I am happy, however, in believing that it is not the opinion of most people.

I have followed in the columns of *The Electrician* the discussion which ensued, and, with reference to Mr. Jacomb-Hood's remarks on the tractive effort formula employed by me in my paper read before the members of the Institution in November, 1900, the estimated initial cost per mile, and the estimated k.w. output, I would beg to observe that, although Mr. Jacomb-Hood is quite correct in his statement that the formula used by me was criticised, no effort was made by any one present at any one of the meetings to replace it by any deduction which might be considered more accurate. Since that date, however, the subject has again been very fully investigated by Mr. J. A. F. Aspinall in numerous trials on trains comprising various loads. These experiments, as set forth in Mr. Aspinall's paper read before the Institution of Civil Engineers on November 26, 1901, practically confirm the formula employed by me. I take as an example his curve shown in Fig. 8, Plate 2, for 10 bogie coaches, with the following result as compared with the calculation shown in my Table IV.:—

Mr. Langdon.

	Tractive Effort lbs. per Ton.	
	Aspinall.	Langdon.
Express passenger trains	12·4	13·0
Ordinary " "	6·8	7·1
Express goods "	8·25	7·9
Ordinary goods and minerals ...	5·9	5·5

With respect to the initial cost and the k.w. capacity of the plant, I would also remind the reader that my paper purported to be a comparison between the cost of working a *given section of line carrying an ascertained traffic for a given period*, and consequently it made no provision for additional traffic—it was an estimate based upon the traffic which had been ascertained, and which was given in the paper.

Mr. Bennett.

Mr. F. F. BENNETT, in reply (*communicated*): Mr. Sayers takes me to task for not calculating the power required for the various gradients, curves, and for not making a due allowance for windage, for the whole of the English and Welsh railways. Does Mr. Sayers know what this would mean? There are 15,308 miles of railway in England and Wales. How would it be possible to make this calculation for a paper of this description? Assuming that the plans and sections were obtainable, the work of arriving at the result desired by Mr. Sayers would take an indefinite period, and would fill volumes. My calculation embraces only the running on the straight and level; to this I added 100 per cent. for total losses, and an additional 75 per cent. (goods and passenger). Surely this margin was sufficient for overcoming gradients, curves, and windage. How do my figures compare with the actual results obtained by Mr. Aspinall of the Lancashire and Yorkshire Railway? These tests indicated the absorption of 8·337 lbs. traction effort per ton. Mr. Langdon's calculation for a train travelling at 50 miles an hour was 13 lbs. traction effort per ton. My calculation in my paper was, for a train travelling at 40 miles per hour, 9·4 lbs. traction effort per ton. There is not a very great divergence in these figures, and, if I have erred at all, it has been on the right side. Mr. Sayers enumerates certain of the congested or "fat" districts, and implies that all other, or "thin" districts, would work at a loss, because the load-factor would be a poor one. Is he correct in this statement? I am not only inclined to think that he is not, but I am certain that the load-factor, of what he terms the "thin" districts, would not be a poor one. If you take 235 miles of any portion of the English railway system, you will find that there would always be several trains running at one time; furthermore, the number of trains would be of a most even character, so that a good load-factor would obtain. In the early days, it was said of electric lighting that it was all right for large towns,

Mr. Bennett.

but that for small towns it would not pay owing to the poor load-factor that must necessarily obtain; experience, however, has not borne out this result. We have load-factors in small areas as good as those in the large electric-lighting areas, and this argument stands good for railway electrification. Mr. Jacomb-Hood selects two of the most important four-section main trunk railways in the country (50 miles and 80 miles), and argues that because these sections require 10,000 and 20,000 k.w. respectively to work them electrically, my average of 11,000 k.w. for 235 miles is wide of the mark for the whole of the English and Welsh railways. Mr. Jacomb-Hood cannot be in earnest in implying that the traffic on the Cambrian Railway, or that on the Lancashire, Derby, and East Coast Railway, and on many branch single-section lines, should absorb anything like the power absorbed by the fifty-mile section out of St. Pancras, or the main trunk line from Waterloo to Southampton. If he were to calculate the power necessary for working the whole of the London and South-Western system, including the branch lines, single-section lines, etc., the result he would find would not materially differ from the figures contained in my paper. I also differ from Mr. Morrison's view, viz., that we have now arrived at the maximum speed on English railways. The average speed of 20 miles an hour for local trains, and 29 miles an hour for long-distance trains, strikes me as being extremely low, and, in my opinion, it could be safely and conveniently increased. I do not admit that I am wrong in my calculation in coal consumption. The load-factor in a railway power centre should be quite as good as that obtaining in an ordinary tramway power centre. I allow 0·1705 pence per k.w., whereas the coal consumption at Glasgow is 0·18 per k.w., at Huddersfield 0·14 per k.w., at Newcastle 0·14 per k.w., at Sheffield 0·18 per k.w., at Liverpool Overhead 0·20 per k.w., an average consumption of 0·168 pence per k.w., which is 0·0025 pence in my favour. My opinion remains unshaken as to the ultimate adoption of power-station areas common to all railway companies; and that any other method of distribution will end disastrously to the undertakers.

The President.

The PRESIDENT: Mr. Bennett is not present, and we can only have a written reply to the discussion; but I have no doubt that you wish to pass a vote of thanks to him for his contribution.

The vote was carried by acclamation.

The PRESIDENT announced that the scrutineers reported the following candidates to have been duly elected, viz.:—

Members.

Jörgen Björnstad.
Edward Hardcastle.
Edward May Munro.
James Gilbert White.

Associate Members.

George Henry Baker.
Robert S. F. Bayntun.
Andrew W. Blake.
Thomas M. Cairns.
Ernest J. Constable.
Frederic W. Dennis.
William C. H. M. Georgi.
Richard Gill.

Associate Members (cont.).

Lionel B. Hogarth.
George D. A. Myers.
Percy Olver.
Francis C. Polden.
Herbert B. Tilley.
Reginald D. Timmins.
John Tweedie.
William E. Warrilow.

Associates.

Edwin Eager.
Leonard A. Emerson.
James Lord.
Harry B. Shutes.
John P. Strange.
Charles K. Stretch.
Daniel Williams.

Students.

Joseph W. Anson.
William Brooker.
Bernard E. Ellson.
Hedley Hughes.
Harold Schluter.
Charles E. Sexton.

NEWCASTLE LOCAL SECTION.

EXPERIMENTS ON EDDY CURRENTS.

By W. M. THORNTON, D.Sc., Member.

(*Paper read at Meeting of Section, December* 14, 1903.)

§ 1.—EXPERIMENTS ON MASSIVE CAST-IRON AND STEEL RINGS.

Eddy currents are induced in solid masses of metal by any variation of a magnetic field traversing them. The loss of efficiency of dynamo-electric machines from this cause can be approximately determined from the fact that while other losses caused by hysteresis and mechanical friction vary directly with speed, eddy-current losses are proportional to its square. The usual way of conducting the separation test is to run the machine light, at the same excitation but at different speeds, as a separately excited motor, and to plot the current taken by the armature vertically, the brush voltage or speed horizontally. A line is obtained which cuts the vertical axis, and the current required to overcome the eddy-current loss is the height of the line above a horizontal through this point of intersection. Measured in this way eddy loss is found to account for 25 to 50 per cent. of the loss of efficiency at light load. (Hawkins and Wallis: "The Dynamo," third edition, p. 689.) The increased loss at full load depends very much on the construction of the machine. It is greater with soft iron poles and pole-faces of high electrical conductivity than with cast iron, because the circulation of the local eddies varies not only inversely with the specific resistance, but as the square of the permeability. It is for this reason that they are much greater in iron than in copper, for the ratio μ^2/ρ is 500,000 times greater for the former than the latter at ordinary flux densities. A comparatively small variation of magnetisation will therefore give rise to strong currents when they are permitted to flow.

Before examining in detail the losses in a machine, it is well to know how eddy-current loss is related to hysteresis and copper losses in the most perfect case—that is, of a massive closed iron ring covered with a uniform winding and excited by an alternating current. For this purpose it is only necessary to measure the current taken and watts absorbed by the coil under different conditions of excitation and at different frequencies. Tests were made on two yoke rings (Fig. 1), kindly lent by Messrs. W. H. Allen and Co., the hysteresis loops of which have been determined by a special method independent of the influence of eddy currents in the core. Each ring was connected in turn first to the supply mains at a frequency of 83, and then to

experimental alternators giving either 18 or 37 periods per second. The results are recorded in Table I. and in Fig. 2A.

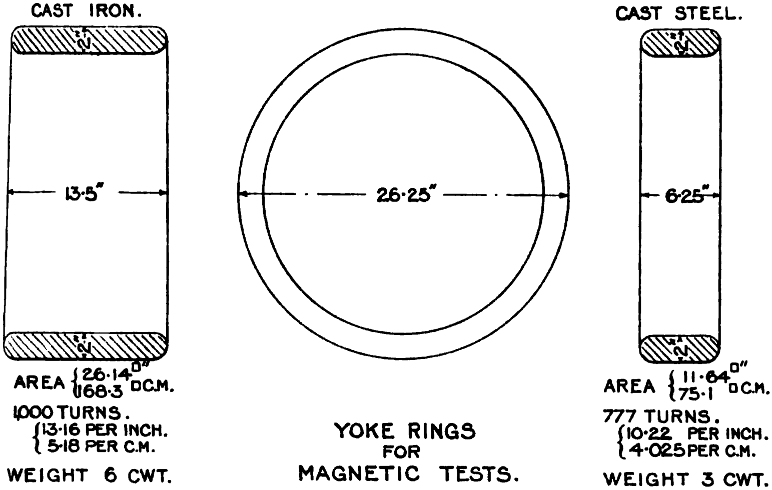


FIG. 1.

TABLE I.—CAST-STEEL RING.

Volts.	Amperes.	Watts.	Cos ϕ	$\sim$	$r\,i^2$	Hysteresis Watts.	Eddy Watts.	$\frac{\text{Eddy}}{\text{Hysteresis}}$.	$\frac{V}{A}$. ohms.
31·8	0·71	22·6	1·0	83·5	0·96	15·4	6·2	0·4	44·7
42·0	1·0	41·5	0·99	83·5	1·9	27·3	12·25	0·45	42
60·7	1·5	84·2	0·93	83·5	4·27	39·0	41	1·05	40·5
81·5	2·0	148	0·91	83·5	7·6	40·4	100	2·47	40·7
100·0	2·8	254	0·90	83·5	14·9	43	196	4·55	35·7
25·0	1·1	27·5	1·0	13·3	2·3	5·6	19·6	3·5	22·7
76·5	4·2	289	0·9	15·8	14.2	14·2	241·3	17	18·1
80·5	5·39	392	0·9	19·0	19·7	19·75	317	16	14·9
89·0	6·25	502	0·9	18·8	20·2	20·2	407·3	20·3	14·5
CAST-IRON RING.									
100	0·67	60·5	0·9	83·5	1·3	21	38	1·8	149
37	0·39	13	0·9	37	0·44	8·6	4·3	0·5	95
45·2	0·534	21·4	0·89	37	0·83	12·5	8·0	0·64	85
102·5	0·782	68·4	0·84	37	1·78	49·6	17	0·34	132

Much difficulty was experienced with the cast-iron ring in getting consistent readings. This was found to be due to the retentiveness of the iron. The highest alternating voltage available in the laboratory is 100, and not having a suitable transformer the greatest current reached at the highest frequencies was 0·67 ampere. The power-factor was found by the oscillograph and the watts calculated, but there is little practical interest in these very low magnetisations. Typical oscillo-

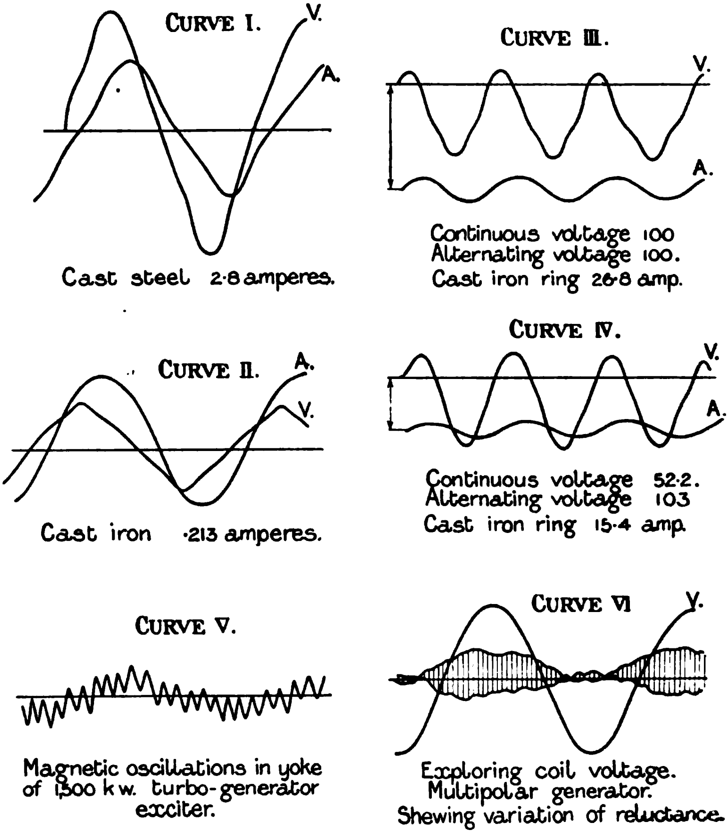


FIG. 2.

grams are given in Curves I. and II. (Fig. 2). By an inspection of the tables and Fig. 3 it will be seen that as losses increase the power-factor decreases. This cannot be due to the increase in permeability, for that is higher at the lower magnetisations. It means that with small coil currents the eddies are sufficiently great on account of the high values of μ to prevent waves of any strength entering the core. When the whole core is magnetised by the large coil currents the loss by eddy currents is increased, not because of their greater intensity, but of the larger area of the core brought into activity.

It is interesting to compare the behaviour of the two rings. The area of the iron ring is 2·25 times that of the steel. Its permeability is about one-half; the ratio of the turns on the windings are as 1·285 to 1. The inductance of a coil with a laminated core being

$$L = 4\pi T^2 A \mu / l,$$

where T is the total turns, A the cross-sectional area of the core, μ its

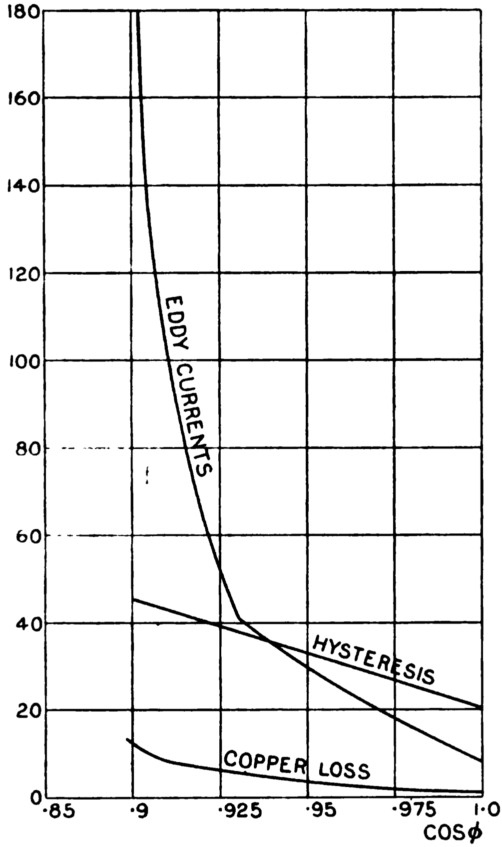


FIG. 3.—Cast-Steel Ring.

permeability, and l its mean length, the corresponding inductance of the iron ring is 2·84 henries, which is 1·44 times that of the steel. The resistance of the "iron" coil is 2·9 ohms, that of the steel 1·9. These are too low to affect the impedance, and the inductances would with laminated cores be in the ratio 1·44 to 1. They are actually 5 to 1.

Table II. shows how the cores are affected and their magnetic properties inverted by the action of the eddy currents. It may be pointed out in passing that the energy dissipated in any eddy-current

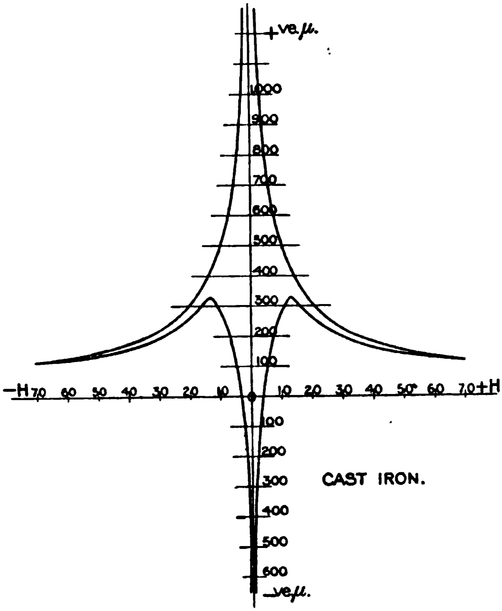
path is proportional to the square of the voltage along it, but the voltage is itself proportional to the rate of change of induction or other things being constant to μ. The loss at any point in the core is therefore proportional to $(d\mu/dt)^2$ at that point. The variation of μ with time is not generally considered, but a conception of its change can be obtained by drawing a μ H curve instead of the usual μ B relation, as in Fig. 4, and allowing H to vary according to a simple sine law from a positive to a negative maximum.

TABLE II.

—	Cast Iron.	Cast Steel.
Mean permeability from loops	$\mu_1 = 260$	*520*
Calculated inductance	2·84	1·98
Observed impedance	149	30·58
Resistances of windings	2·9	1·9
Frequency	83·5	83·5
Observed inductance	0·445	0·058
Actual permeability of cores as a whole ...	$\mu_2 = 40$	*19·8*
Ratio μ_1/μ_2	6·5	26·3
Frequency	37	13·3
Observed impedance	132	18·1
Observed inductance	0·57	0·034
μ_2	51·5	11·7
Ratio μ_1/μ_2	5·05	44·5

Cases of solid cores exposed to alternations of this kind are rarely met in practice, but it is common to find a solid framework carrying a flux density less than saturation exposed to alternations of rapid frequency and considerable amplitude, as, for example, in the magnetic circuits of alternating-current machines. Some effects of these oscillations have been given in former papers,* and the tests made on the Hastings plant show that they are present under the best conditions of practical working. To imitate such cases, I placed an alternator in series with a continuous-current generator across the coil windings, obtaining Curves III. and IV. (Fig. 2). In the larger of the two with 100 volts alternating superposed upon 100 volts continuous, the effect of the core in distorting the voltage wave is seen as a third harmonic. The current variation has an amplitude of about *12* per cent. of the mean reading, and *17* per cent. when the continuous voltage is reduced to *50*. The maximum disturbances of field currents observed in practical working were *22* per cent. of the steady value in single-phase, *15* per cent. in three-phase machines, the average being about 10 per cent. The ring experiments (Table III.), therefore, approximate to the conditions of practice, and it may with reason be inferred that the losses will be in much the same ratio and of the same order of magnitude in similar yoke rings and magnet cores.

* *Journal I.E.E.*, vol. 32, p. 573, and *The Electrician*, September 4th, 1903.


+ve μ.
1000
900
800
700
600
500
400
300
200
100
−H 70 60 50 40 30 20 10 0 10 20 30 40 50 60 70 +H
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−ve μ.
CAST IRON.

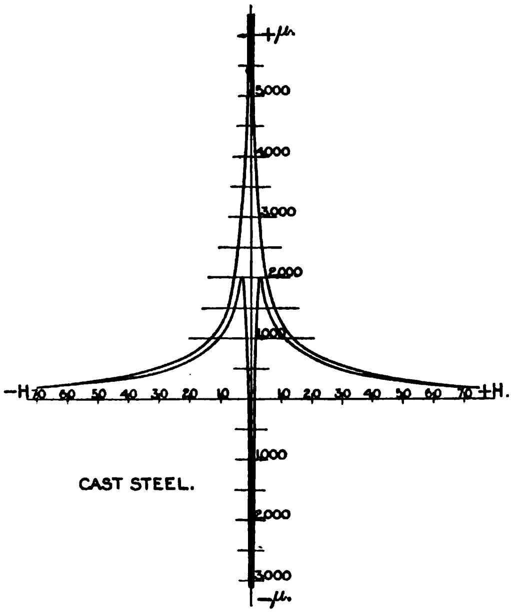

+μ
5000
4000
3000
2000
1000
−H 70 60 50 40 30 20 10 10 20 30 40 50 60 70 +H.
1000
2000
3000
−μ
CAST STEEL.

FIG. 4.

TABLE III.

Continuous Voltage.	Alternating Voltage.	Combined Voltage.	$\sim$	Amperes.	Watts.	Cos ϕ.
52·2	103	112	86	15·4	853·4	0·485
100	100	138	86	26·8	2,410	0·65
H continuous.	**H alternating.**	**Hysteresis Watts.**	**$r\,i^2$.**	**Watts Eddy-Current.**	**Per cent.**	**Eddy-current Watts per c.c. of core.**
89·6	10·4	3·5	690	180	21	0·055
156·2	26·6	0	2,080	330	12·4	0·101

To separate the continuous from the alternating current components, the oscillograph records were necessary. The ammeter reads $\sqrt{(I + i \sin \theta)^2}$, and by knowing the relative values of i and I from the curves, their average values can be separated. Thus when the ammeter read *26·8*, 24 was continuous and 4·08 alternating. The combined voltage was taken with an electrostatic instrument. It is seen that the intensity of the continuous magnetisation is so great that the hysteresis loop is closed for the range of alternating current employed. There is, nevertheless, a wave of magnetisation accompanying each reversal of the alternating component, which, though the permeability is comparatively small, still entails a certain loss in the core, amounting in the second case of Table III. to *330* watts, or 12·4 per cent. of the whole energy dissipated, and in the first case, when the permeability is slightly greater, to 21 per cent.

§ 2.—Tests of Continuous and Alternating Current Machines.

From these results it can be concluded that if in any machine the field current shows a synchronous variation, caused by armature reaction, of about 10 per cent., there will be a loss in the core by eddy currents which may be a large fraction of the total losses in the machine.

In the experimental machine tested the total volume of the two magnet cores and yoke is 30,000 cubic centimetres, all of which is exposed to varying magnetisation, though not of the same amplitude. Running it as a shunt motor, light, and varying the speed, the eddy-current loss at *1,150* revolutions per minute is found to be *480* watts. Now, the energy lost by eddy currents in an iron core varies as the square of the alternating ampere-turns applied to it, but the secondary voltage in an exploring coil about the core is proportional to the

primary ampere-turns. By measuring the exploring coil voltage under various conditions of working, the magnetic movements producing eddy currents within the core can be gauged. Table IV. gives a few results obtained in this way, the deflections being those of a hot-wire galvanometer placed across the series turns. When the brushes were central, very little deflection was observed. They were, therefore, moved backwards until commutation took place in the fringe from the trailing tip and slight sparking was visible. They were fixed in this position during the tests. The disturbing influence of the armature current is seen by the great increase in the square in Column 6 with load when the fields are weakened. Why there is any deflection at all is a question which will be answered in Section 3. The deflection obtained when the machine was running light as a motor with the brushes forwards to the same angle that they were previously backward was $\theta_0 = 8{\cdot}2$, with an armature current of nine amperes. The figures in the last column give the relative eddy-current losses in a loaded generator to those in a motor running light, which are given above.

Table IV.—Continuous-Current Generator Speed. 1,120 Revolutions per Minute.

Field Current.	Flux Density in Gap.	Voltage.	Current.	Deflection. θ.	Square of Ratios of θ.	$\left(\frac{\theta}{\theta_0}\right)^2$
			0	6·25	1·0	0·59
3·7	5,100	128	30	8·5	1·85	1·07
			51	13·0	4·3	2·5
			72	18·0	8·3	4·8
			0	1·55	1·0	0·03
2·7	4,475	110	30	4·5	8·4	0·3
			50	8·0	26·5	0·95
			71	12·0	60	2·15
			0	0·65	1·0	0·006
1·7	2,980	75	30	3·2	24·2	0·15
			51	6·0	85	0·53

It is difficult to imagine a loss of 2,300 watts by eddy currents in a 10-k.w. machine even with the brushes far backward. The last column of figures must stand for what it is worth as a test of the method, but it was thought well to devise another, and the method adopted was to pass an alternating current through the series windings and to measure the power at different currents or frequencies. *Vide* Table V.

Applying the graphical* method of separating hysteresis and eddy-current loss, the three components have been worked out. It is reasonable to suppose that in this case practically all the eddy currents circulate in the solid frame, for it is certain that those in the laminated

* See Appendix I., p. 554.

armature are exceedingly small compared with the circulation in the solid core around which the magnetising coil is placed. According to this table, it takes about *2,000* ampere-turns applied to the coil at a frequency of 83 to produce eddy-current loss comparable with that observed in a motor running light.

TABLE V.

Volts.	Amperes.	Watts.	Cos ϕ.	I T.	$r\,i^2$.	Eddy Current Watts.	Hysteresis Watt.	Ratio Eddy /Hysteresis.
86	41·4	2,300	0·64	4,554	69·8	1,975	255	7·7
56·8	26·2	900	0·60	2,882	28·0	790	82	9·6
43	17·75	468	0·61	1,952	12·8	363	92·2	3·9
25·5	11·9	220	0·72	1,310	5·6	163	51·4	3·18
18·25	8·05	115·5	0·78	885·5	2·6	74·5	38·4	1·94
12·1	5·27	50·2	0·78	579·7	1·1	31·9	17·2	1·85

TABLE VI.—ALTERNATING-CURRENT GENERATORS. SPEED, 1,120 REVOLUTIONS PER MINUTE.

—	Field Current.	Volts.	Line Current.	Watts.	Cos ϕ.	θ.
	3·7	81	0	0	—	0
Single-phase	"	75	33·5	2,460	1·0	04·85
	"	71	52	3,700	1·0	14
	"	69	60	4,050	0·98	19·5
	2·7	52	335	1,740	1·0	6
	"	47	47	2,260	1·0	13·1
	1·7	35	33	1,160	1·0	4·7
Three-phase	2	44	25	1,640	0·75	0·5
	"	40	37	2,220	0·75	0·5
	"	37	55	3,040	0·75	0·85

Before proceeding to consider the causes of eddy-current trouble it may be of interest to show by Table VI. the behaviour of the same machine as an alternating-current generator. The internal disturbance when working single-phase is greater than in continuous generators, but with three-phase currents much less, and it is known that the efficiency of the machines is greater in the latter case.* If the greater part of the eddy-current loss takes place in the armature, *why should three-phase working be so much better than single for the same machine ?* To show that it does not, a single-phase current was passed through the armature by way of the slip-rings, and the losses separated by the method given in the appendix. The magnitude of the hysteresis loss in ordinary

* *Journal I.E.E.*, vol. 32, pp. 583 *et seq.*

working can be found with accuracy, and is 10 per cent. or more of the total losses, so that the eddy-current loss in the armature may be taken from the table in the appendix at about 3 per cent. But the total eddy-current loss for a continuous-current machine is about 30 per cent. of the whole. The remaining 27 per cent., or practically all, must, therefore, take place in the solid magnet frame.

§ 3.—Oscillograms of Magnetic Field Disturbance by Variation of Armature Reaction and Reluctance.

It has been shown that large eddy-current loss can take place in the magnet frames of both continuous and alternating current machines. In the latter class the chief source of the loss is, no doubt, variation of armature reaction; but in the former the conditions have been generally thought to reach a steady state, or one in which the magnetic movement is confined to the armature teeth or pole-faces.

There are in continuous-current machines four possible sources of disturbance; the first and most important at light load being imperfect centring of the armature or adjustment of the air-gaps. The second is the variation of reluctance caused by the teeth of the armature moving across the pole-face. The third is the slight peripheral shift of the cross magnetising belt to and fro during commutation; and the last the variation of reaction set up by a rise and fall of armature current, caused by phase swinging or uneven turning moment of the engine.

In my last year's paper it was shown that imperfect centring caused double-frequency waves of magnetisation in the solid cores when the armature was revolved mechanically with no current of any kind in its windings. During some experiments at Neptune Bank station it occurred to me that the magnetic circuit of the exciter of the recently-installed 1,500-k.w. turbo-generator might show signs of internal movement. An exploring coil of 10 turns was, therefore, wound around the yoke of the machine, which is bipolar, mounted on the end of the turbine shaft, and itself separately excited from the main exciter 'bus-bars. The remarkable result is shown in Curve V., Fig. 2. There are two effects present, one synchronising with the three-phase current generated in the main circuit, the other with commutation in the exciter. The generator has four poles and a revolving field. The oscillograph motor was driven from the main supply, and the cause of the wave in the curve must be looked for in something which goes through a cycle in half a revolution of the shaft. The current leaving the exciter showed no such wave, but only a small irregular ripple evidently set up by the three-phase reaction. The disturbance must, therefore, arise within the exciter, and it is not difficult to see that such an effect can only be produced by a slight eccentricity of the armature on its shaft, so that when the hump is opposite either pole the reluctance of the exciter circuit is least, and when between them greatest, causing a reaction at double the speed of the exciter—that is, synchronising with the main supply. The superposed ripple has 15 periods to that of the wave, and therefore coincides with the frequency of commutation, for the exciter has 30 segments. The machine delivers 210

amperes at 30 volts, and the demagnetising ampere-turns vary by about *125* during each short-circuit. For let the angle covered by one brush be θ, then when commutation is perfect there is a change of current from a positive to a negative maximum in that space. By unfastening one of the connections to the commutator and joining the ends to two slip-rings, the brushes of which are then connected by a low resistance, this change of current can be observed in an oscillograph. Fig. 5 is a typical curve from a machine with wide carbon brushes. The current falls rapidly to zero and grows slowly to its opposite maximum.

Let the point of passing through zero be after 0·06 of the brush angle has been traversed, then the entering current will be rapidly falling while the leaving current is rising, the effect in cross ampere-turns being the same as if the former persisted at its full value for an angle 0·03 θ then suddenly ceased, and the latter reached and maintained it about 0·7 θ before release. There is, therefore, a resultant peripheral shift of the cross ampere-turns equal to the mean of these effects, or about 0·36 ϕ i_a C/360; where C is the total number of conductors on the armature. Taking $\theta = 20$ deg., there is for the exciter an oscillating

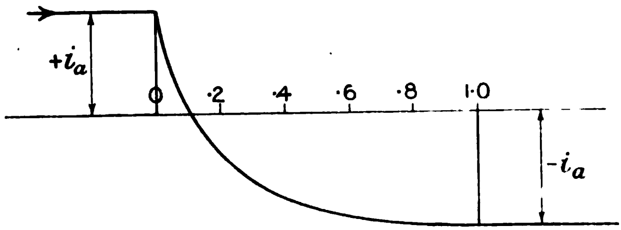


FIG. 5.—Oscillogram of Current in Coil Short-circuited by Brush.

peripheral variation of about $0·36 \times 20 \times 105 \times 60/360$, or 123 ampere-turns. This may not appear great, but in a low-voltage machine it may be an appreciable fraction of the total winding ampere-turns. In this case it is sufficient to disturb the whole magnetic circuit to the extent shown. The section of the yoke is 8 in. × 14·5 in., and it is of cast iron, in which, as we have seen, there is comparatively small damping by eddy currents. The effect is not likely to cause much loss by core heating, but it is this further evidence of disturbances in the magnetic circuits of large commercial machines constructed with great accuracy which leads me to regard them as universal, and as a general source of loss of efficiency.

To illustrate the extent to which these oscillations set up in commutation affect the magnetic circuit, I connected the series coils of a Pallion six-pole generator, which has a steel frame and poles and cast-iron shoes, to the hot-wire galvanometer. The machine was then run separately excited at constant load and the brush position varied. (There is a slight permanent reaction caused by the armature running out of centre by an amount too small to be observed. This variation of reluctance can be seen in Curve VI., Fig. 2, where the voltage in an exploring coil placed about the bobbins varies between

the limits of the shaded area in time with the speed of the machine, the oscillograph motor running at three times the speed. This is a confirmation of the cause of the wave in the Wallsend curve, though it was in that case stationary on the screen, the speeds being identical.) Any increase of voltage can then only be due to the change in the magnetising ampere-turns during commutation, for this is the only thing which is varying. It is seen from Fig. 6 that when the brushes are rocked backward until there is sparking there is an active movement within the core, which, when they are forward, is much less. Both curves show signs of rapid changes of considerable amplitude. To investigate this further, the resistance connecting the experimental slip-ring brushes was removed and the two adjacent commutator segments short-circuited by a copper bridge. One coil of the armature then acts as an exploring coil, the voltage in which is at every instant proportional to the strength of the field through which it is passing.

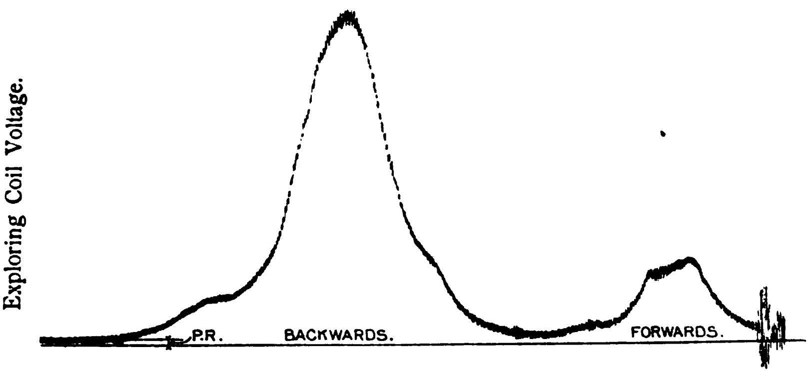


FIG. 6.—Effect of Brush Position on Magnetic Movement within the Poles.

The rings were then connected to the oscillograph, and a few of the results are recorded in Fig. 7.

These curves are of interest as being, I believe, the first to show the instantaneous distribution of polar magnetism in dynamo-electric machines. Their full consideration must be reserved for another occasion. It is seen, however, that when the brushes of a generator under load are moved backwards the magnetism in the gap is caused to oscillate at a speed much higher than that of the machine, and in ripples. These are in a state of oscillation, the amplitude of which is greater with strong fields and for brush positions which correspond to commutation taking place in a strong field. The effect does not depend upon sparking at all, for in the fifth curve there was scarcely any, while in the second, with brass brushes, it was very heavy both in the forward and backward positions. These brushes were narrower than the carbon, and the peripheral shift is therefore less. In generators or motors the ripples are strongest at the pole-tips with the most stray field.

It may therefore be concluded that of the four causes given, the first and third are active in producing eddies. The second is known to be

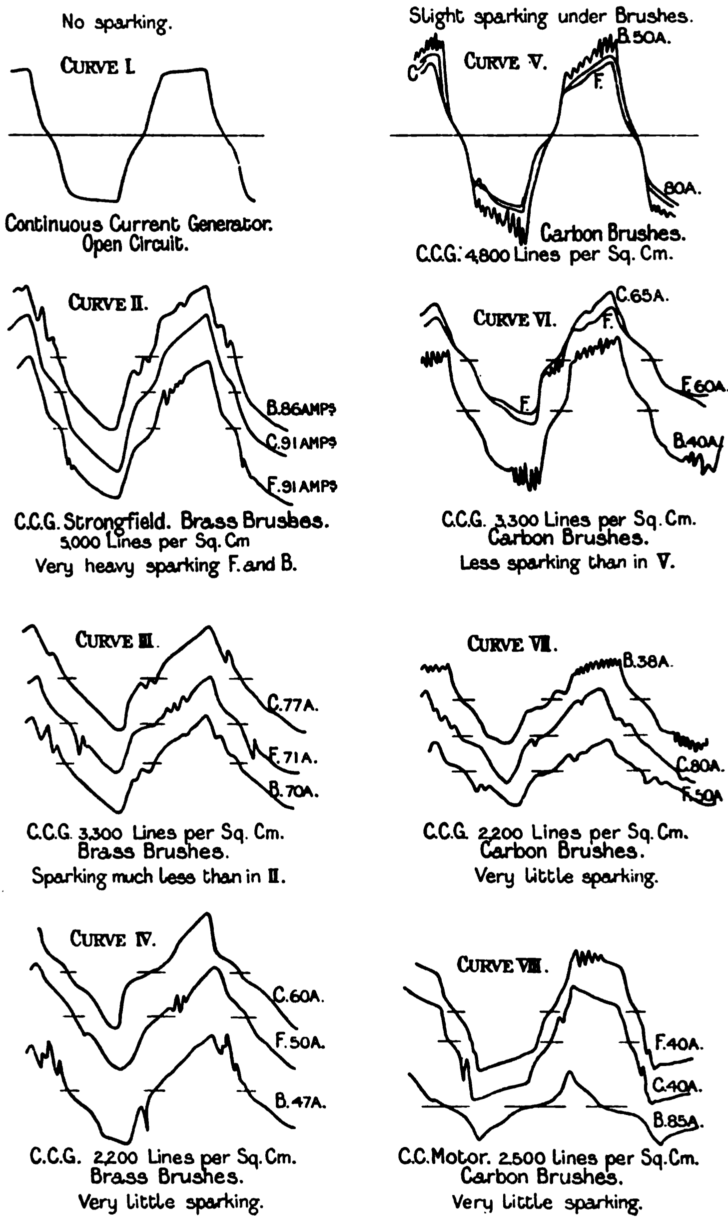


FIG. 7.—Magnetic Field Distribution.

by the heating of pole-faces with slotted armatures. It remains to examine the effect of the last.

§ 4.—Influence of Periodic Irregularity of Armature Rotation and of Unequal Turning Moment in Prime Movers.

The first three may be regarded as internal in their origin, the armature swinging as external. It is peculiar to certain classes of alternating-current machines. Synchronous motors and rotary converters, even when provided with damping devices, have free periods of oscillation, so that a sudden change of load or a synchronous engine speed will start the system swinging about some position of stability. This phase swinging, as it is called, is known to set the field ammeters fluctuating in time with the disturbance. There are, therefore, waves

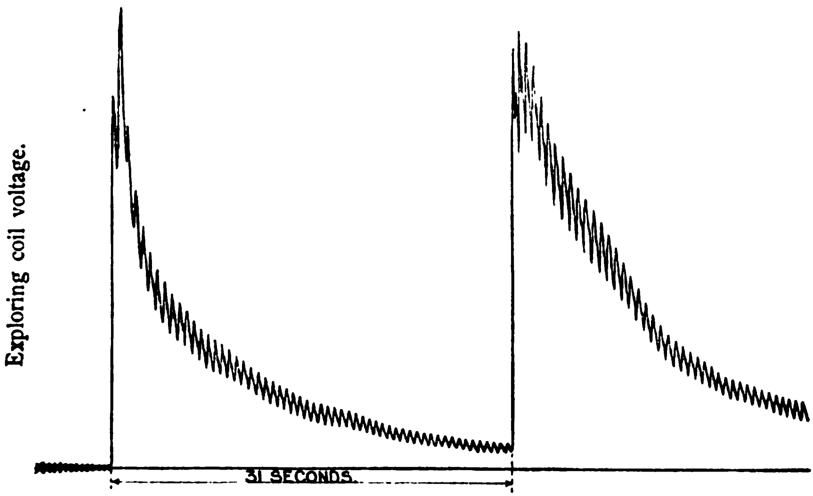


Fig. 8.—Disturbance of Pole-flux by Phase Swinging.

of magnetisation of low frequency, but great intensity, sent into the poles from the armature, and the consequent loss of energy there is material in reducing the oscillation. Since the armature currents are changing at a high frequency at the same time as they are fluctuating, there is a two-fold effect on the field while the swing persists, the more important of which is not that caused by the slow hunting swing itself, but by the increased armature reaction. To examine this, the hot-wire instrument was connected to an exploring coil on a converter field delivering single-phase current to a second converter, and through it to a non-inductive resistance. This load was suddenly thrown on and off, with the result that both machines started a phase swing, which by reason of the eddy currents induced in the magnet frames was reduced to $1/e$-th of its initial value in about three seconds. The relative magnitudes of the two reactions is shown in Fig. 8, which is a photograph of the induced exploring coil voltage. The swing fre-

quency is 120 per minute, sufficiently removed from the speed of the engine, 74 a minute, to show that it is a true phase-swing effect. The ordinates of the curve are a measure of the coil voltage which sets up eddies, though these are proportional to the square of this, which explains the rapidity of the damping. Loss from this cause is not in any case persistent, and is in a sense a direct advantage, but it is closely allied with one which is the most serious cause of eddy currents of all which have to be considered.

Irregularity of turning moment in an engine driving either continuous or alternating current generators causes the armature currents to vary in time with the period of the engine, and the whole distribution system may be set swinging together, entailing a loss in the mag-

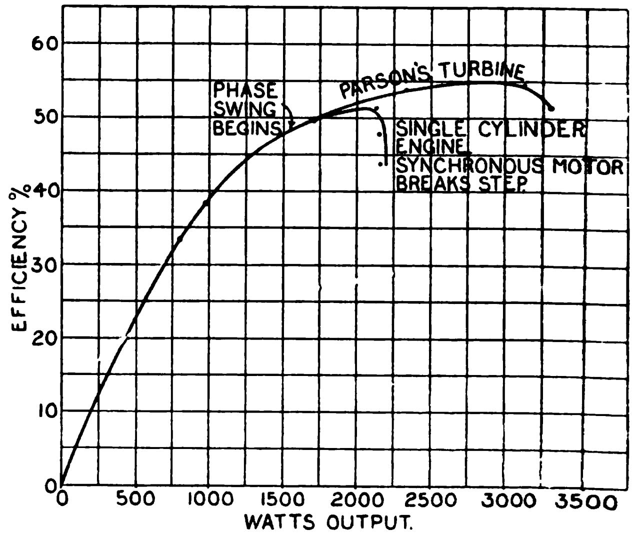


FIG. 9.—Influence of Irregular Turning Moment on Efficiency of Transmission.

netic circuits of every synchronous motor or converter connected to the mains, and only differing from that of Fig. 8 in its persistence. In other words, it is a forced vibration started and maintained by the engine. Fluctuations of current in time with the engine can be seen in any large alternating-current supply system; even turbines are not quite free from this source of loss, unless the puffs of steam admitted by the governor are too rapid for the machines to follow. With the old throttle type of governor this does not occur.

Some experiments made last year may be of interest in showing that the efficiency of a transmission system supplied from turbo-generators may be several per cent. higher than from reciprocating engines. The two converters in the laboratory were connected single-phase, as in the former experiments. They were then driven by continuous current—first, from a turbo-generator, and afterwards from a single-

cylinder double-acting engine with a heavy flywheel. Measuring the input and output by carefully calibrated "Precision" wattmeters, it was found that in the former case the output was higher than in the second, as shown by Table VII. and Fig. 9.

TABLE VII.—TURBO-GENERATOR.

Volts Input.	Amperes Input.	Amperes Output.	Watts Input.	Watts Output.	Efficiency. Per Cent.
80	30	9	2,400	800	33
80	44	23·5	3,465	1,720	49·7
72	58	35	4,360	2,330	53·4
85	72	44	5,770	3,135	54·4
82	84	50·5	6,400	3,300	51·6
Single-Cylinder Engine.					
72·5	32	12	2,480	940	37·9
71	45	23·5	3,190	1,560	48·9
71	59	32	4,150	2,140	51·6
65	71	39	4,550	2,150	47·6
64	76·5	43·7	4,950	2,220	44·9
63·5	80	42	4,960	2,150	43·3

There can be no question of wattmeter error, for the tests were purely comparative, and under exactly the same conditions of excitation and speed, but by applying the oscillograph to the fields of the machine in each case, a difference in the amplitudes of the exploring coil voltage was observed. The ratio of the root mean square values at full load is 1·03. Since eddy losses are proportional to the square of this, the difference is explained as caused by extra eddy currents in the poles and magnet frames set up by the swinging of the armature currents in each of the motors when driven off the single-cylinder set. This disturbance was so great that the second machine broke step at loads corresponding to the sudden droop in the efficiency curve; whereas, when driven by the turbo-generator, very little fall is to be seen at loads 50 per cent. greater. The case, no doubt, represents the two extremes of engine regularity; but many large gas-engine plants show more fluctuation on load than does our 75 H.P. single-cylinder engine. It is fitting that these results should conclude this paper. I am now sure that if one had the time and opportunity to conduct a series of experiments on widely different types of machines, by building them first with solid, then with laminated poles and yokes, the same result would be reached—viz., that it is in the large solid iron masses of any machine that the greatest unlocated dissipation of energy takes place.

APPENDIX I.

The Separation of Eddy-Current and Hysteresis Loss in Armatures.

The armatures being removed from the magnets, alternating current is passed through the windings, and measurements are made of the frequency, power, and current. The current can be led into alternating stators by the ordinary terminals, and into continuous ring armatures by temporary brushes set about half one pole-pitch apart. The reason for this in the latter case is to cause differential magnetisation and ensure an oscillatory circulation of magnetism. With drum armatures there is no necessity for this, and two of the ordinary brushes

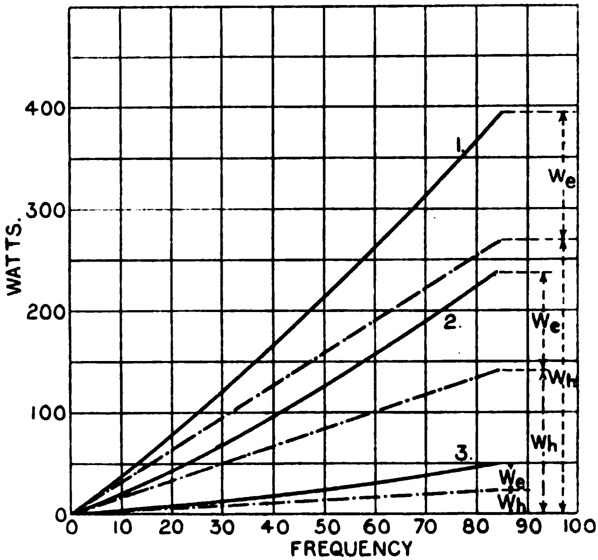


FIG. 1A.—Separation of Iron Losses in Armatures.

can be used. The current should be as large as possible, though if the heating is excessive it is difficult to get steady readings simultaneously. Dead-beat direct-reading instruments should be employed. On account of the comparatively low flux densities reached when the core is magnetised in this way, the greater part of the power is absorbed in heating the windings. Of the remaining iron loss the hysteresis component is proportional to the frequency, the eddy-current loss to its square. The iron loss may then be written

$$w = \alpha\, n\, B^{1.55} + \beta\, n_2\, B^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

which, by using the same current at all frequencies, reduces to the form

$$w = a\, n + b\, n^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Using two frequencies n_1 and n_2, the ratio of the hysteresis loss to the eddy loss is

$$\frac{W_h}{W_e} = \frac{w_2\, n_1^2 - w_1\, n_2^2}{n(w_2\, n_1 - w_1\, n_2)},$$

and

$$W_h = a\, n = \frac{(w_2\, n_1^2 - w_1\, n_2^2)}{n_1\, n_2\, (n_1 - n_2)}.n$$

$$W_e = b\, n^2 = \frac{(w_2\, n_1 - w_1\, n_2)}{n_1\, n_2\, (n^1 - n_2)}.n^2$$

TABLE VIII.

—	Curve.	Amperes.	Watts.	~	$r\,i^2$	Iron Loss.	W_h	W_e	$\frac{W_h}{W_e}$
10-k.w. ring armature.	1	61	180	7·5	165	15	13·5	1·5	9
		61	200	14·7	165	35	27	8	3·37
		61	400	84	165	235	140	95·5	1·46
	2	81	360	11·5	310	50	42	8	5·25
		81	706	85·2	310	396	270	125	2·16
5-k.w. ring.	3	17·48	342	16·7	335	7	5·5	1·5	3·6
		17·48	385	83·5	335	50	25	30	0·83

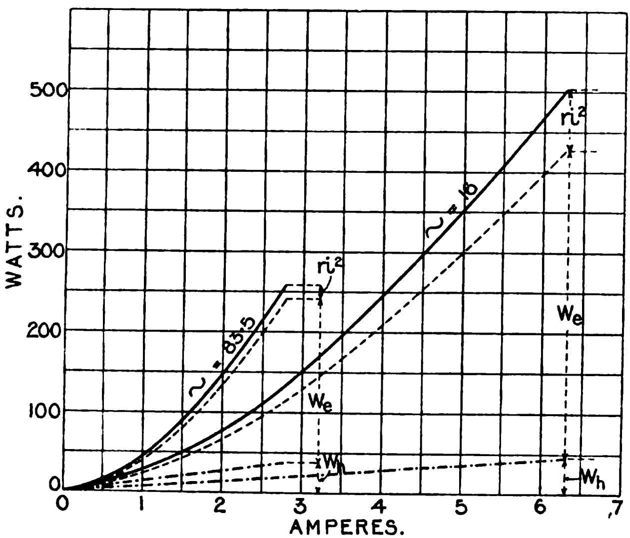


FIG. 2A.—Increase of Core Loss with Magnetising Current in Solid Rings.

But the separation can be more easily and accurately made by a graphical method. Plotting power as ordinate and frequency as abscissa, it is seen from (2) that the total height of the curve is the sum

of the ordinates of a straight line $W_h = a\,n$, and a parabola $W_e = b\,n^2$, both of which pass through zero. A tangent to the plotted curve at this point divides all ordinates into two parts, the upper giving the eddy-current, the lower hysteresis loss.

The following table gives the results of tests on a 10-k.w. ring armature having an iron volume of 9,050 cubic centimetres, and on a smaller one of 1,000 cubic centimetres.

In every case but the last the hysteresis loss is greater than the eddy-current, even at the highest frequencies, and by comparing Fig. 1A with Fig. 2A, which is for the solid rings of Section 1, the value of lamination in reducing eddy losses is seen by the smaller curvature near the origin.

APPENDIX II.

To trace the cause of the field ripples some further experiments were made, the results of which are given in Fig. 3A.

In Curve VI., Fig. 2, at the end of the paper, was shown the magnetic disturbance through an exploring coil around one pole. The wave oscillated at the speed of the machine, and it is found it *does not change in amplitude* from no load to 25 per cent. overload, so that the eddy loss due to variation of reluctance can be taken as constant. In the Curve 3, Fig. 3A, the ripples are barely seen (though the curve may be magnified ten times by projection) when the brushes are central, even on full load. They are therefore *not caused by passage of the core teeth.*

When the brushes are in the neighbourhood of either pole-tip the rapid field ripples, Fig. 3A (2), appear *before any sparking is visible.* They are therefore not an effect of sparking, but indicate its cause, viz., the reaction of the armature current on the steady field. This is twofold in nature—the leakage fringe is blown to and fro by the passage of the conductors, and the peripheral shift of the conductor during commutation causes a small alternating magnetisation at the frequency of commutation.

The variation in position of the lines producing the changes of voltage which cause the ripples can take place anywhere on the conductors between two brushes. The peripheral shift only causes the current rectangle to oscillate sideways (an effect which can be readily observed, for the ends of the rectangle are always slightly blurred) without affecting its height, but both the internal and external currents show the same vertical ripples. *See* Fig. 3A, curves 1 and 5.

In perfect commutation the current emerges from or enters the brush without shock. The characteristic feature of commutation in a strong field is the sudden release of lines which in collapsing affect the main induced voltage, and if great enough, cause a small portion of the current to leap across the mica, producing sparking. It is this inductance voltage which no doubt causes the ripple in the armature voltage or current at the frequency of commutation. The amplitude of the ripple in the magnetic cores, Curve 3, Fig. 3A, does not greatly increase when the machine is loaded, and it must therefore be regarded as

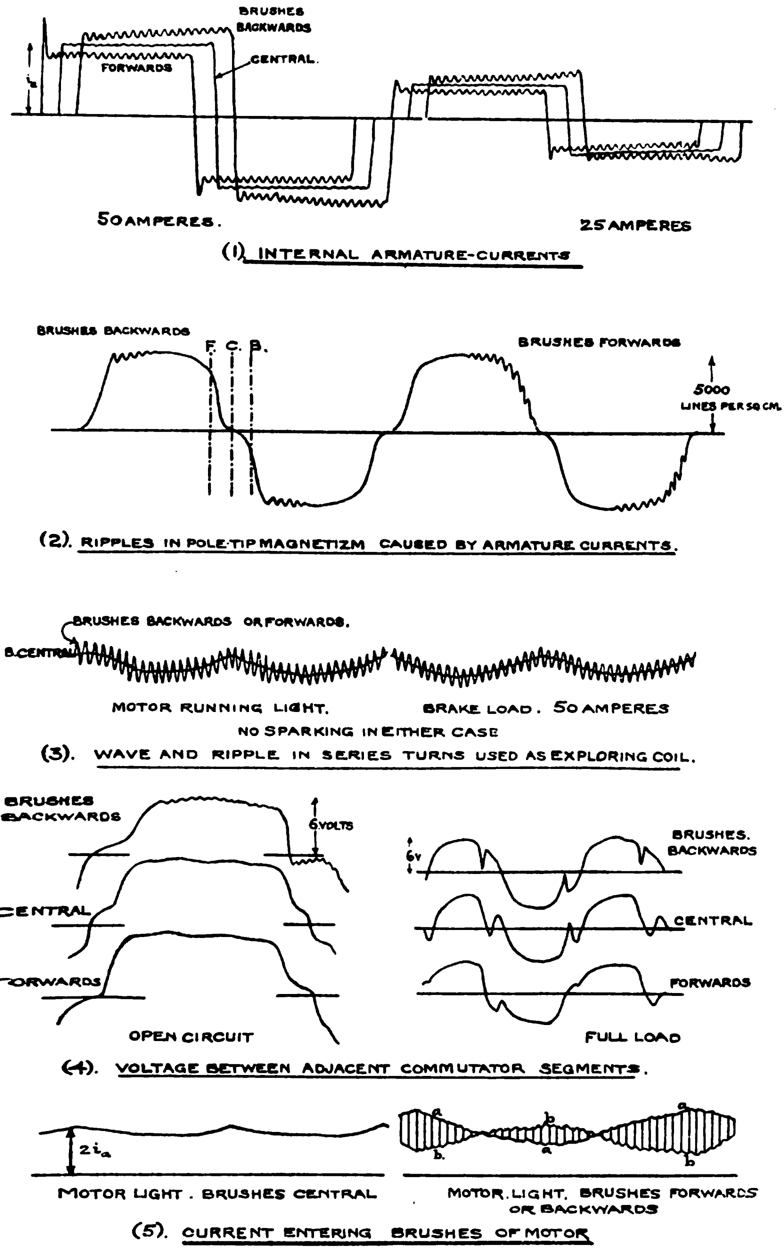

BRUSHES BACKWARDS
CENTRAL.
FORWARDS
50 AMPERES.
25 AMPERES
(1) INTERNAL ARMATURE-CURRENTS
BRUSHES BACKWARDS
F. C. B.
BRUSHES FORWARDS
5000 LINES PER SQ CM.
(2). RIPPLES IN POLE-TIP MAGNETIZM CAUSED BY ARMATURE CURRENTS.
BRUSHES BACKWARDS OR FORWARDS.
B. CENTRAL
MOTOR RUNNING LIGHT.
BRAKE LOAD. 50 AMPERES
NO SPARKING IN EITHER CASE
(3). WAVE AND RIPPLE IN SERIES TURNS USED AS EXPLORING COIL.
BRUSHES BACKWARDS
CENTRAL
FORWARDS
6 VOLTS
OPEN CIRCUIT
6v
BRUSHES. BACKWARDS
CENTRAL
FORWARDS
FULL LOAD
(4). VOLTAGE BETWEEN ADJACENT COMMUTATOR SEGMENTS.
2ia
MOTOR LIGHT. BRUSHES CENTRAL
a
b
MOTOR. LIGHT. BRUSHES FORWARDS OR BACKWARDS
(5). CURRENT ENTERING BRUSHES OF MOTOR

FIG. 3A.

caused more by the position of the brushes in a strong field than by peripheral shift. As they stand the curves can scarcely be compared, for the amount of brush movement necessary to produce the ripple shown is less when on load. In each case the brush was placed where sparking was about to begin. A surprising effect is seen in Curve 5, for in a multipolar machine with a distributed winding one would scarcely expect to find the external current to show a wave having a frequency twice that of the machine. Yet by comparing Curves 3 and 5 at all loads the correspondence is so close that one must conclude that they have the same origin. No such wave was observed in the external current of the bipolar machine first tested. Small air-gaps render machines very sensitive to slight imperfections in construction, and one would expect to find in large rotary converters, where there is also the alternating-current reaction, a state of very active magnetic disturbance. Curves 4 were obtained by winding copper wire upon asbestos and mica to form a temporary slip-ring over the commutator and connecting it to one segment, the adjacent one being already joined to a special slip-ring. They are of interest as showing the voltage between two segments, more especially the influence of commutation in a strong field. The positions of the brushes are seen by the sudden drop at right angles to the zero line. The strength of the reversing field and the change of voltage at the end of short-circuit can be observed in this way.

Mr. Eugene-Brown.

Mr. E. EUGENE-BROWN said this was the third paper Dr. Thornton had given to the Institution in three sessions, and he must say it was quite as original as the others. It contained the result of a tremendous amount of work. For himself, he must confess that, although he had read the paper several times, and studied several points in it, he had not yet been able to get all out of it. Taking into consideration the number of factors that went to make eddy currents, it seemed hardly possible to get anything tangible to put on paper. When the shape of the field, permeability, specific resistance, magnetic screening, periodicity, and also leakage had to be taken into account, it was very easy to imagine the complexity of such a question. Dr. Thornton has given figures taken from actual machines, and he found in some instances the loss was very great indeed. Dr. Thornton says it is difficult to imagine a loss of 2,300 watts by eddy currents in a 10 k.w. machine. It seems an enormous loss, and one would be tempted to say that this was a case where eddy-current loss was particularly bad. The experiments require to be gone through many times, and the figures and methods closely scrutinised before coming to a conclusion. Dr. Thornton tells us that the loss in the armature by eddy currents is very small indeed; this fact should be very carefully thought over, it depended to a large extent on the care taken in building up the core. With manufacturers, the eddy-current losses were generally taken from the curves obtained somehow or other, and often they accept the experiments made in the laboratory, or workshops where they had

a laboratory. They generally found in practice that these losses by eddy currents and hysteresis were more than they got from the curves. In the field magnets they had neglected eddy currents entirely. He had never heard it suggested that eddy-current loss took place in the yokes of machines. He thought it was the experience of every one in testing dynamos that the pole-pieces heat. In many cases, if care is not taken to have the slots narrow enough, it has been found that the heat is very considerable. He had seen machines where the pole-pieces were the hottest parts before alterations were made to obviate this, but as far as he could see, Dr. Thornton was the first to point out that the eddy-current loss of any considerable value took place in the field magnets. Mr. Eugene Brown.

In multipolar machines the eddy-current loss may be slightly different to two-polar machines, inasmuch as the magnetic circuit is not entirely broken. He thought the disturbance would be greater in the two-polar, although he was not certain of that. In the experiments that were made on these yokes, he thought Dr. Thornton must have made them mainly for the sake of finding out the effect of eddy current in circuits of similar machines; but, of course, this would be nothing like what it would be in multipolar machines, as in these tests the magnetic circuit was entirely closed without a gap. But it would be extremely interesting to see the differences in the various periodicities, and he thought when this was thoroughly scrutinised it will give some knowledge of the value of eddy currents. The paper was a most valuable one, and when some definite values, which could be used in designing, were obtained from the formulæ, it would be found to be extremely useful. At present the subject was so complex that they were not able to calculate any particular case.

The oscillograph will tell us more of the internal losses in dynamos than any method brought out yet, and probably the improvement of the instrument will lead to very great results.

Mr. A. W. HEAVISIDE said he did not think he was competent to discuss Dr. Thornton's paper. He thought that only people who have gone through the great labour that Dr. Thornton has, and also manufacturers who are acquainted with the practical side of the question, could satisfactorily discuss the paper. All he could do was to make a few general remarks. Mr. Heaviside.

The application of the oscillograph, directed by the scientific genius of Dr. Thornton, had given a peep into the mysteries of intangible electricity in the interior of dynamos, and when they are better known and better developed they will lead to good results. The great thing, in his mind, was to be symmetrical in all things electrical.

He then related some of his experiences in connection with his work as Superintending Engineer of the Post Office Telegraph Department, to illustrate the importance of attention to apparently small details applied to the telephone in particular and to high-class telegraphy in general, which responded to everything going on in their environment, whether it was electric lighting, traction, or power.

Mr. Heaviside.

Experience showed that as the electrical industries had to live side by side, when undue disturbances occurred that it was only by frankness in the explanation of the cause that future trouble was most easily avoided; as usual, each had to concede something.

Mr. Ralph.

Mr. GEORGE RALPH said being engaged in the manufacture of electrical machinery, it seemed to him that the most important practical point brought out in the paper was the necessity of very exact centring of the armature in its field.

Mr. Proctor.

Mr. C. F. PROCTOR said it was to their loss that they had not had the time to go into these matters, but they should make the time to go in for experiments. Papers like Dr. Thornton's pointed out directions in which they might improve their machines. A careful study of the fluctuations pointed out would repay them well. Such a valuable paper should have a fair discussion. It was a valuable paper to them, and shows that manufacturers should give more time to these matters.

Mr. Law.

Mr. A. L. LAW said that one great point of interest to him in Dr. Thornton's paper was the proof it gave of the utility of the oscillograph in continuous-current as well as in alternating work.

With regard to heating in field magnets his experience agreed closely with that of Mr. Brown, and he had always been accustomed to regard the mass of the field magnets as cold iron which could be relied upon to a large extent to carry away the heat of the magnet windings, and this assumption seems to be fairly justified by experience.

These remarks do not apply to pole-pieces, where in most cases there is bound to be some tendency to eddy-current loss.

Mr. Stoney.

Mr. GERALD STONEY said the Institution was much indebted to Dr. Thornton for bringing such a valuable paper before them, which helped to clear up many of the obscure phenomena occurring in dynamos and alternators. So far as he knew, no one before had shown what actually occurred in the coil of continuous-current armature during commutation, and investigations like this would probably lead to the much better understanding of the phenomena of commutation, many of which were very obscure. The effect of carbon brushes in rounding off all the irregularities of the curves was very marked, and thus securing sparkless commutation under difficult conditions, but it by no means followed that it was not possible to secure the same with brass wire brushes when a suitable reversing field was provided, and in the case of the more recent turbo-generators this had been so successfully accomplished that sparkless commutation was secured without shifting of the brushes from no load to 50 per cent. overload, and 100 per cent. overload could be taken for a short time without injurious sparking.

The reactions in the field caused by changes in the current during commutation were most interesting and would come as a surprise to most electrical engineers, and it was evident from Dr. Thornton's investigations that large losses might be caused in this way in the field magnets. But in ordinary practice with well-adjusted brushes the losses from this cause would be small, as modern generators tested by the Hopkinson method often give about 94 per cent. efficiency, which with the known losses due to hysteresis and eddy currents

Mr. Stoney.

the armature, together with the C^2R losses, windage, exciting and friction, leaves small margin for losses due to eddy currents in the fields. It is evident, however, that these may become very serious in cases where there is heavy sparking, which results from the rapid changes of current during commutation, as in the case of Dr. Thornton's 10 k.w. motor, and this is confirmed by the fact that in some cases the steam consumption of a steam-driven generator has been found to be greater where the brushes were not properly adjusted.

In practice it is exceedingly difficult to separate the various losses in a dynamo or a motor, as given at the beginning of the paper, as although we know the hysteresis to be proportional to the speed, and the eddy currents proportional to the square, the friction varies according to little-known laws, and the windage up to even the cube of the speed, so that tests made at various speeds are not very reliable unless that at each speed a test is made without exciting to determine the windage and friction losses, which means driving by a separate motor of which the efficiency has to be determined at the various speeds by a brake test. Something can also be done by determining, in the case of a motor or a dynamo running light as a motor, the watts required at various amounts of exciting, keeping the speed in each case constant, and making these sets of determinations at various speeds; but the whole thing becomes so complicated, and there are so many corrections to make that these tests are very uncertain, and in any case give no information as to the losses at full load, and it seems likely that a great deal may be done by Dr. Thornton's method of looking for oscillating magnetism in various parts of the machine. Where such oscillating magnetism is found the source must be looked for, and the cause, if possible, removed or reduced. In the case of alternators especially, this is likely to be of value, and it is quite possible that we may see some further lamination of the field magnets, and that the damping necessary for parallel running may be given by suitable damping coils instead of, as in many instances, by more or less solid poles. In this connection Dr. Thornton shows well the importance of even turning movement, and the tests made on the motor generators at the Manors sub-station showed there was a decided loss due to the reciprocating engines at the Neptune Bank power-station not having an even turning moment in comparison with the more even turning moment of the steam turbines. It is evident that losses must thus be caused through the whole system, and this is the case both with alternating and continuous current.

Dr. Thornton has chiefly dealt with the losses in the field magnets, but there is much of interest in the losses due to hysteresis and eddy currents in the armature plates. If we calculate the loss in an armature by the hysteresis, as found by the ballistic method, and by the eddy currents on the usual assumption of the currents passing up one side of the plate and down the other, we find the actual losses to be usually three or four times as great. This is partly due to the uneven magnetic density in the core of the armature, and tests were made some years ago showing that in a multipolar armature with an average density of 8,000 C.G.S. lines per square cm., the density may be as great as 15,000

Mr. Stoney. on the outside and only 3,000 on the inside; but it is also partly due to the fact that iron subjected to a rotating magnetic field has at ordinary densities very much more loss than when subjected to alternating magnetism. It has been pointed out by Prof. Ewing in his "Magnetism in Iron and other Metals," and by Prof. S. P. Thompson in his "Dynamo Electric Machines," also by Messrs. Hawkins & Wallis in "The Dynamo," that the cycle in an armature is different from that

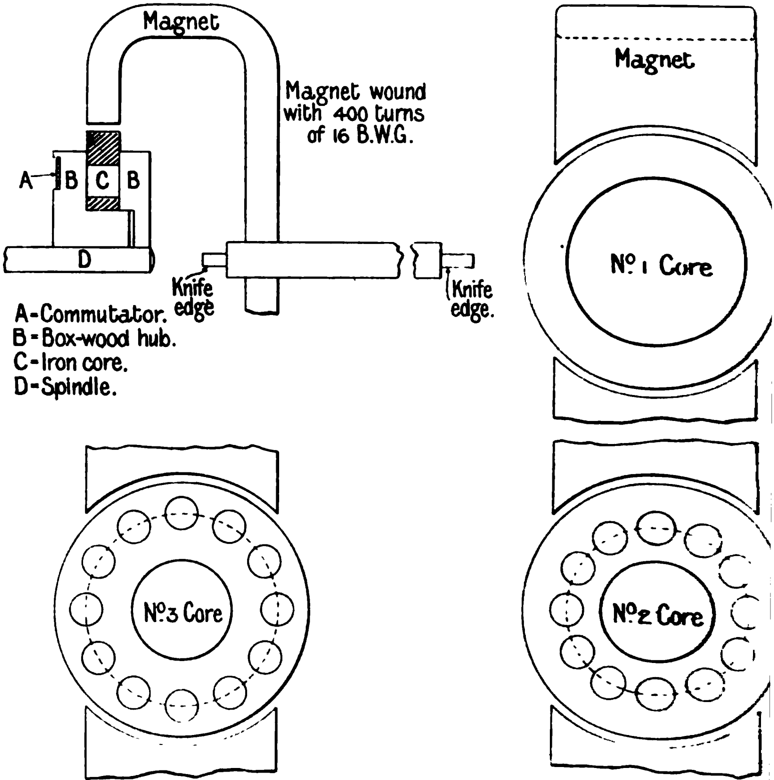


FIG. A.

in a ring or rod, which in turn is similar to that in a transformer. Prof. F. G. Baily (*Phil. Trans. R.S.*, 1896) has carried out a series of experiments on this point, and shows that in a core with only a small hole in it the hysteresis curve does not obey the $B^{1 \cdot 6}$ law, but up to $B = 10,000$ is about 50 per cent. more, whence it gradually approaches the value given by the $B^{1 \cdot 6}$ law up to about $B = 15,000$, after which it rapidly decreases and is zero at about $B = 21,000$ or at saturation, which result was predicted from Ewing's theory of molecular magnets.

Some years ago the speaker carried out a series of tests on cores with large holes in them, magnetised by bipolar magnets, by a similar

arrangement to that used by Prof. Baily, and he found that up to about B = 8,000 the loss was from two to three times that which would be expected from the usual $B^{1·6}$ law. It is much to be desired that tests should be carried out at higher densities, but at the time this was the limit he could go to with the apparatus at his disposal, and there has as yet been no opportunity to take up the investigations again, but sufficient was done to show that the shape of the core had large influence on the Mr. Stoney.

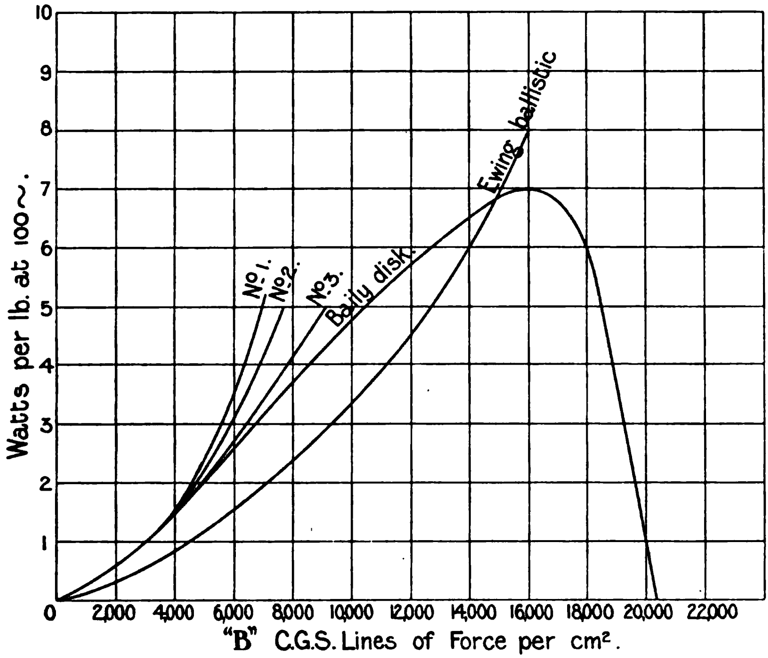


FIG. B.

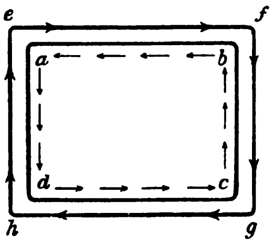
hysteresis loss. It is to be hoped that somebody, with more time and opportunity at his disposal, may take up this interesting part of hysteresis and eddy losses, a fuller investigation of which might have important results in the way of increasing the efficiency of dynamos and alternators.

With reference to the exciter of the Parsons Turbo-Alternator at Neptune Bank, one point should be mentioned. The armature is mounted on a sleeve, and originally ran quite true, but it was taken off for some purpose or other, and when replaced ran slightly out of truth, probably owing to a small piece of dirt on one side of the sleeves. This might account for the ripples in the magnet limbs. This will be set right at the first opportunity. It is very possible that investigations by the oscillograph may lead to a better understanding of the effect of altering the number of segments on commutation, a thing about which very little was known at present.

Mr. Holmes. Mr. J. H. HOLMES, in rising to propose a vote of thanks to Dr. Thornton, said he had been particularly interested in the paper, but most of the points which had come into his mind had already been touched upon. The very pretty application of the oscillograph demonstrating what goes on in one coil of the armature when it is undergoing commutation was very interesting. Experiments on large machines might show the right number of commutator segments to have on a machine.

Mr. Field. Mr. M. B. FIELD (*communicated*): It is highly important to differentiate clearly between the laws of eddy-current losses in the laminated and solid portions of dynamo machines.

If we subject a laminated core to an alternating magnetic force of which the amplitude is H at the surface of the laminations (the laminations being, of course, in the plane of the magnetic flux), the loss per cubic cm. will, if the lamination be sufficiently fine, be proportional to $H^2\mu^2n^2/\rho$, where μ is the permeability, n the frequency, and ρ the specific resistance, and the magnetic induction will have a constant value at every point of a section transverse to the plane of lamination. In the case of solid masses, however, the law is quite different. Let *a b c d* be the cross section of a long core surrounded by a magnetising coil. We will consider a core of considerable dimensions, say, for sake of argument, 6 inches square.



Suppose an alternating current be flowing in the magnetising coil, the direction of the current at some particular instant being that denoted by the arrows *e f g h*, then we know that currents in the opposite direction will circulate in the skin of the solid core. The effect of these skin currents is, of course, to screen the interior portion of the core from the magnetic effect of the magnetising coil, which they do by exercising an opposite or neutralising magnetic force. The result is that the interior portion is quite unaffected by the magnetising coil, and the magnetic effect and eddy currents are entirely confined to the skin portions, unless, of course, the frequency of alternation be very low indeed.

It is easy to see that the higher the permeability, the electric conductivity, and the frequency, the smaller will be the depth to which the magnetic effect will penetrate. For example, in iron, where the permeability is high, and with a frequency of, say, 30 per second or over, the eddy currents and magnetic effect will be extremely small at a distance of more than one or two millimetres below the surface.

As the interior portions are free from both eddy currents and magnetism, no loss will occur there, and therefore the loss in the core does not depend directly on its volume, for we could change its shape considerably, thereby altering the volume, but by keeping the superficial side area the same we should not materially alter the hysteresis and eddy-current loss.

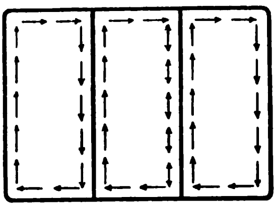
As we have seen, the total volume of iron to which the losses are

confined depends on the exterior surface, and in some way inversely as the permeability, electric conductivity, and frequency, with the result that instead of a law such as Total volume × $H^2\mu^2n^2/\rho$, we have very nearly Total side area × $H_1^2\sqrt{\mu n \rho}$, where H_1 is the maximum value which the magnetic force reaches at the surface of the core. This is a very important point, as we see that it is incorrect to talk of the eddy-current losses per unit volume of solid masses, and moreover since the laws are different in solids and laminæ, we cannot apply the same method to separate out the hysteresis from the eddy losses in solids as is applicable for the laminated portions. Mr. Field.

The total flux in the solid core can be shown to be proportional to B_1 and to $1/\sqrt{n}$, where B_1 is the maximum value of the induction at the exterior surface; hence if we surround the core with an exploring coil the E.M.F. induced in it will be proportional to $B_1\sqrt{n}$ and its square to $B_1^2 n$. The loss, as explained above, is proportional to $B_1^2\sqrt{n}$, and hence it follows that the one cannot be taken as a gauge of the other unless the fluctuations of B_1 follow a true sine law. It is therefore necessary to use great circumspection in adopting the exploring coil nethod of gauging the eddy losses in solid magnet limbs, as proposed ›y Dr. Thornton. Those interested in this subject will find a further iscussion of this and other points in the paper in the *Electrician* during 'ebruary of this year.

Another point worth calling attention to here is that, if we wish to parate the eddy-current from the hysteresis loss of an armature ıder practical conditions, we must employ a method by which we ve not only the same total flux but the same flux distribution, since se losses do not depend to the same degree on the induction.

It is interesting to observe that if we apply a given alternating gnetic force to an iron core we may ıally increase the eddy and hysteresis by laminating—in fact we may in- se it enormously. For example, if we up the core illustrated above from slabs insulated from each other, we ld have eddy currents circulating in in of *each* slab of the same strength fore, and the total loss would be



e of that if solid. By further lamination the loss would still r increase until a maximum value was reached, and after that decrease towards zero as the lamination was made finer and finer. other interesting point is that since the loss in the solid core per ngth depends on the perimeter, and in the laminated core on the cross section, and (considering similar cores), since the area es faster than the perimeter, it follows that however finely we minate, if we only make the core cross section large enough, ill come a point where the loss, if laminated, will be greater e loss if solid. It therefore becomes important to determine for and shape of core what thickness of lamination will give (under varying magnetic force) the same loss as if there were no ion at all. It is clear that a thickness of lamination less than

Mr. Field. this critical value must be employed if any advantage is to be gained at all. I have had occasion to make calculations in this direction lately, and I hope shortly to publish some interesting and simple rules and figures which tend to show that lamination of the poles and yokes of nearly all the cases Dr. Thornton discusses would actually increase the eddy and hysteresis loss rather than diminish them, unless the thickness of lamination was made very much less than is the standard practice at the present time with transformer makers.

In conclusion, I would point out that the above is only true where the magnet cores are subjected, as stated, to a definite varying magnetic force, and the total induction produced is allowed to adjust itself; in solid cores it will have a relatively small value in laminated cores, a much higher value for the same applied alternating magnetic force. This is an essentially different case to that of the core of a transformer, alternator armature, etc., where the magnetic force is adjusted to force through a given definite total flux, no matter whether there is a great or small choking back effect due to eddy currents. The equations in the two cases differ materially; in the latter, of course, there is no critical value of lamination which gives a maximum loss, but the finer the lamination the less the loss.

Dr. Thornton. Dr. THORNTON, in reply, said: Mr. Brown has referred to the experiments on yoke rings. They were undertaken to find what loss really occurred in solid rings exposed to alternating magnetisation. All the theories of the subject assume the permeability of the iron to be constant, and the calculated depth of the skin effect cannot therefore be the same under practical conditions. The experiments are at least worth quoting, for though the rate of dissipation in the interior is no doubt negligible, at the boundary it cannot be. No one, as far as he knew, has ever investigated theoretically the case of eddy-current distribution caused by variation of air-gap reluctance. The frequency of the large magnetic changes, in all classes of machines, caused by the change of air-gap length is shown by the reaction on the supply current to coincide with the speed of revolution, which may be anything up to 10 a second in large modern types.

The curves obtained in ordinary workshop testing in every case he had seen or taken include all eddy losses both in field cores and armature, and make no attempt to distinguish them. The loss of 2,300 watts is calculated, and the method by which it was obtained is given more to show any one else thinking of it, that it is of uncertain value. It is not used afterwards.

Mr. Heaviside and Mr. Ralph have gone to the root of the matter. To get rid of the greater part of the eddy loss at no load, armature stampings must be true *on the shaft*, so that the air-gap is always exactly the same. The cost of precision would not be great, and as Mr. Proctor has said in effect, it is worth trying to get one per cent. more efficiency.

In reply to Mr. Law, he (Dr. Thornton) would say that large solid frames of continuous-current machines are certainly warmer after several hours' run. This he always used to put down to heat conducted from the exciting coils, and there is no way which he

could see of separating the temperature rises in a reliable manner. The coil heat is much greater than the core heat in any case, and, as Mr. E. Brown has shown, windage plays an important part in the flow of heat into the frame. Dr. Thornton

The Chairman (Mr. Stoney) has referred to the difference between the hysteresis coefficients in rotating and alternating fields, and his own experiments are very interesting, showing as they do the importance of properly placing the ventilation holes. Prof. Baily has also made experiments on an actual armature,* obtaining somewhat lower values than in his first paper, and Messrs. Beattie & Clinker have practically confirmed them. If the eddy-current loss remained the same in rotating as in alternating fields, the foregoing results would increase the ratio of hysteresis loss to eddy loss found from the latter. He did not know of any experiments on eddy currents in thin non-magnetic plates—which would be very useful to have—but Professor Baily calculated that the eddy loss would also be increased. Assuming that the eddy currents flow in rectangular paths, he obtained the formula :—

$$W = \frac{3\,B^2 n^2 t^2}{10^{16}\rho} \text{ watts per c.c.,}$$

t being the thickness of the plates in cms. and n the frequency. Professor J. J. Thomson gives the same loss in an alternating field—

$$W = \frac{1{\cdot}67\,B^2 n^2 t^2}{10^{16}\rho} \text{ watts per c.c.}$$

The eddy loss is therefore 1·8 times greater in a rotating compared with an alternating field, and this ratio is independent of the field density. At a flux density of 8,000 lines per sq. cm. the hysteresis loss, as found from Professor Baily's curves, is 1·54 times greater in the former case. The ratio Wh/We is therefore reduced in the proportion 1·54/1·8 = 0·85. The ratio experimentally determined at a frequency of 20 is (Fig. 1, Curve 1) about 6·5. This value would with rotating fields be 5·5, so that he still made the hysteresis loss in the armature core to be over five times the eddy-current loss. In a static transformer it is about ten times as great.

It may be pointed out here that all experiments on iron loss which involve the mechanical rotation of either armature or field magnets are open to the serious objection that unless the cores of both are quite saturated, and the armature plates are *perfectly* circular concentric with the shaft, there will be a variation of the reluctance of the circuit which will inevitably set up eddies in the solid magnet core. These will of course add to the retarding torque and be reckoned as armature losses. Suppose that the cores are built up of stampings, a variation of a hundredth of an inch in their centring will give rise to a variation of 10 per cent. of the total magnetism, if the air-gap is a tenth of an inch long, and eddies are proportional to the square of the magnetic change. As he had said, a considerable part of the eddy loss, in dynamos and motors, at no load may be caused in this way.

* *The Electrician*, vol. 44, p. 323.

Dr. Thornton.

With regard to Mr. Stoney's remark, that after considering the other losses there is "little left for the field eddies," his (Dr. Thornton's) point was, that although the armature alone may be rotated, it does *not follow that all the energy supplied to it is absorbed in it.* No one, he thought, would contend that the energy by which solid pole-tips and faces get hot is supplied by the exciting circuit, and in running a motor trial it would enter as an armature eddy-current loss. It is the same with the parts of the iron circuit further removed from the gap. Any absorption of energy in them by reason of varying magnetisation must be supplied by the armature, and retards its rotation. The transfer of energy can be more readily seen by considering that the eddy currents flow in what is practically a short-circuited secondary circuit, the magnetic flux through which alternates by reason of rapid changes in the armature reaction and because of the variation of reluctance caused by the armature running out of truth.

(*Communicated*).—Mr. Field has called attention to the well-known shielding effects of eddy currents in cores. He will find the correct formula for eddy-current loss in a solid core subjected to rapid alternating magnetisation in J. J. Thomson's *Recent Researches in Electricity and Magnetism*, p. 321, § 286. It may be written—

$$w = \text{Total side area} \times \frac{\sqrt{n \mu \rho}}{16 \pi} \cdot H^2.$$

When the frequency is low or the core small—

$$w = \text{Total volume} \times \frac{\pi^2 \mu^2 n^2 a^2}{4 \rho} \cdot H^2$$

as shown in § 285. The intermediate case is fully worked out by Heaviside, *Electrical Papers*, vol. i., p. 323.

If the magnetic movements are caused by the passage of the teeth, eddy currents are confined to a thickness of from $\frac{1}{4}$ in. to 2 in. in the pole-face; but curves 1, 2, and 3, Fig. 3A, show that the movements due to commutation penetrate a good deal further. The theoretical results given above are derived by considering the permeability to be constant and the core to be infinitely long. The effect of μ being variable is to increase the eddy loss, which depends on $(d\mu/dt)^2$. Since the poles are short there must be an irregular eddy-current distribution behind the pole-shoes, so that the symmetrical shielding effect will be less.

Taking the case of the least possible loss as given by the first of the above formulæ, and assuming $n = 1{,}000$, $\mu = 800$, $\rho = 12{,}000$, $A = 565$ sq. cm., then $w = {\cdot}11\ H^2$.

If instead of H we write B/μ, where μ is now the permeability of the whole magnetic circuit including the gap and is about 15, a maximum variation of B equal to 200 lines per sq. cm. in the gap will cause a loss of 20 watts per pole or 120 for the whole six-pole machine. To this must be added the loss in the pole-face if the armature core is slotted. Under these conditions it is seen that the solid core loss can be at least of the same order as that in the armature.

Dr. Thornton.

The flux distribution in the alternating-current experiments with ring armatures is the same as under working conditions, for the whole radial depth is fully magnetised, and that is the only condition which matters so far as the *ratio* of hysteresis to eddy-current loss is concerned.

With regard to lamination, it is clear that there is a critical thickness, and it would be well to have a comparison of losses in solid and laminated poles on this point. It must, however, be remembered that the thickness is a function of the frequency, and there are at least two disturbing variables, viz., armature reaction and reluctance, whose frequencies are not the same.

It is approaching the subject from the wrong end to try and prove by calculation that the loss in the solid core is too small for notice This is surely a matter for experiment and not for equations. No amount of proof by means of equations will convince one that there is practically no loss in the solid portions of the magnetic circuit, when experiment has shown that the eddy-current loss in the armature does not account for the total loss of that kind in the machine.

From the experiments of Esterline and Reid (*Science Abstracts*, B. 309, 1904), on iron loss in armature cores, the hysteresis loss in machines is found to be twice the eddy loss at working values of B and *n*. The figures are evidently obtained by a motor method which includes pole-face and solid core losses, so that the armature eddy loss is too large. These results, agreeing as they do with those of Fig. 1A, obtained by a different method, establish the main point of this paper, that wherever the greater part of the eddy-current loss may take place in machines, it is not generally in the armature stampings, where it rarely equals that caused by hysteresis.

In conclusion, I wish to thank the members for their very kind reception of the paper, and two senior students--Mr. R. B. Carr and Mr. G. J. Robinson—for their assistance in carrying out the experiments.

DUBLIN LOCAL SECTION.

THREE-PHASE WORKING, WITH SPECIAL REFERENCE TO THE DUBLIN SYSTEM.

By WM. BREW, Associate Member.

(Abstract of a Paper read at Meeting of Section, Jan. 14, 1904.)

GENERATING PLANT.

In Dublin, we have four star-wound Oerlikon generators—two of 1,000 k.w. and two of 500 k.w. output—driven direct by marine-type compound engines with Corliss valve gear. The principal data of these machines are as follows :—

	1,000 k.w. sets.	500 k.w. sets.
Speed, revolutions per minute	84	94
Number of magnet poles	72	64
Number of coils per phase	36	32
Weight of flywheels and magnets, in tons ...	44	33
Diameter of wheels, in feet	18·3	14·2

The electrical characteristics of these machines are illustrated by Figs. 1 and 2. The curves marked A give the relation between exciting current and terminal pressure. The curves marked B give the short-circuit current of the machines for various values of the exciting current. The synchronous impedance of these machines, or the relation between terminal volts on open circuit to short-circuit current at the same speed and excitation, can be read at once from these curves; it will be seen that the short-circuit stator current with an excitation which would produce full terminal potential difference of 5,000 volts is in the case of the 500 k.w. sets 148 amperes. The curve (Fig. 3) is interesting in this respect, and shows how the exciting current necessary to maintain full terminal pressure of 5,000 volts on one of the small Dublin sets varies according to the length of three-core cable connected on open circuit. In this case the alternator is only supplying a charging current to the cable.

Between the generating station at the Pigeon House Fort and the central distributing station at Fleet Street, a distance of 3·1 miles, three trunk mains have been laid. Each of these mains consists of a three-core, lead-covered British Insulated and Helsby Company's paper cable, the section of each core being 0·15 square inch. Samples of these and other polyphase cables are before you.

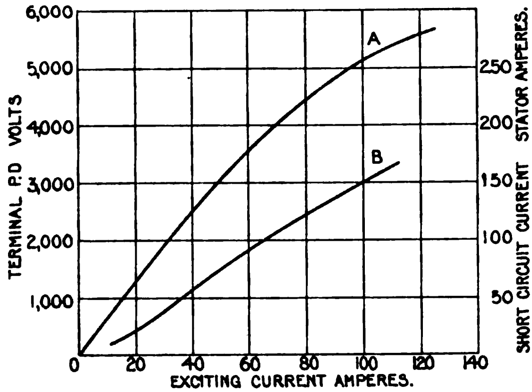


FIG. 1.—Dublin 500-k.w. Generator, 3-Phase, 50 ∿, 93·5 R.P.M.

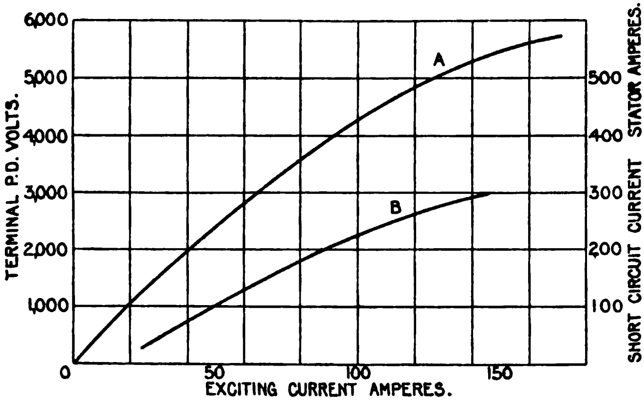


FIG. 2.—Dublin 1,000-k.w. Generator, 3-Phase, 50 ∿, 84 R.P.M.

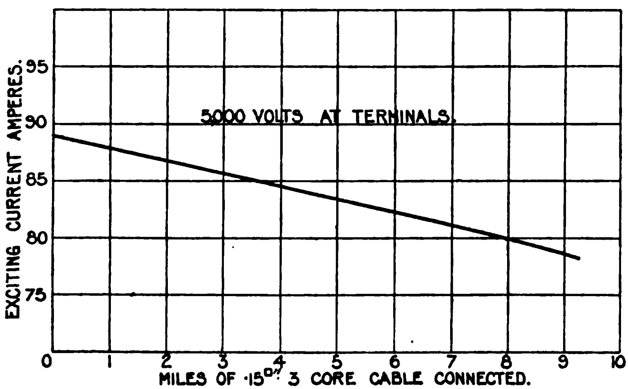


FIG. 3.—Dublin 500-k.w. Generator, 94 R.P.M.

TRUNK MAINS.

TABLE I.—Test of Impedance of 6·2 Miles of (Three-Core 0·15) Extra High-Tension Feeder at 50 ∿.

P.D. between phases at sending end.				Current per core at sending end.			Impedance per single core.
V_1	V_2	Mean.	$\frac{\text{Mean}}{\sqrt{3}}$	C_1	C_2	Mean.	
89	88·5	88	51·2	26	25	25·5	2·01
90	90·5	90·5	52·2	26	25·5	25·75	2·03
99	99	99·5	57·2	28·5	28	28·25	2·02
108	108	108	62·5	31·5	31	31·25	2
116·5	116	116·5	67·2	34	33·5	33·75	1·99
119	119	118·5	68·6	34·2	34	34·1	2·01
						Mean =	2·01

One phase was disconnected, and the following readings were taken :—

P.D. between phases at sending end.		Current per core at sending end.			Impedance per single core.
$V_1 - V_2$	$\frac{V}{2}$	C_1	C_2	Mean.	
92	46	22·5	22	22·25	2·07
100	50	25	24	24·5	2·04
99·5	49·75	25·5	24	24·7	2·02
110·5	55·25	27·5	26·5	27	2·04
122	61	31·2	30·5	30·8	1·98
123·5	61·75	31·5	30·7	31·1	1·99
140	70	35·7	34·5	35·1	2
141	70·5	35·8	35	35·4	1·99
				Mean =	2·01

Capacity tests made upon these feeders after they were laid gave the following results :—

High-Tension Feeders, 0·15 *Square Inch Three-Core Extra High Tension Paper Cable, Lead Covered.*

	Feeder No. 1.		Feeder No. 2.	
	3·13 miles.	Per mile.	3·13 miles.	Per mile.
One core against two other cores bunched to lead sheath ...	0·95 mfd.	0·303	0·95	0·303
Three cores bunched against lead sheath	1·53 mfd.	0·49	1·53	0·49

With the generator coupled to two-trunk feeders in series the readings in Table II. were obtained. It will be noticed that the charging current per core considerably exceeds the theoretical minimum value. This current, however, includes leakage from two large switchboards, one at either end of the line, and newly erected.

TABLE II.—Test of Charging Current of Trunk Feeders, Three-Core, 0·15 Cable, 6·26 Miles total. 0·50 ∾ .

P.D. between cores.	P.D. to neutral point.	Charging current, amperes.		Equivalent capacity of one core.
		Elec. dynmtr.	Kelvin balance.	
1,600	924	2·09	2·2	0·813
2,100	1,212	2·88	2·74	0·735
2,500	1,442	3·37	3·24	0·745
3,200	1,850	4·12	4·14	0·713
3,700	2,135	4·47	4·5	0·667
4,200	2,430	4·85	4·79	0·637
4,900	2,830	4·34	5·19	0·62
5,180	2,990	5·6	5·48	0·597

Sub-Stations.—In the case of three-phase sub-stations we have a variety of combinations of plant open to us. For instance, the trans-

formers may be connected in delta or star on both high-tension and low-tension sides, or delta on one side and star on the other. Then, again, three single-phase transformers may be used one on each phase, or one

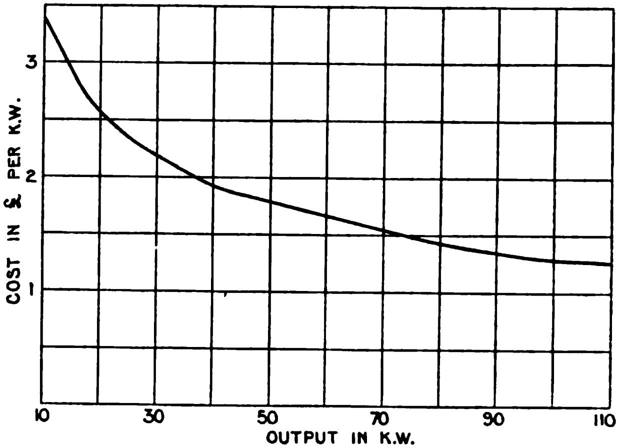


FIG. 4.—Transformers.

single three-phase transformer may be used to take the place of the three single-phase transformers. In any particular case the considerations governing the choice of single-phase or three-phase transformers

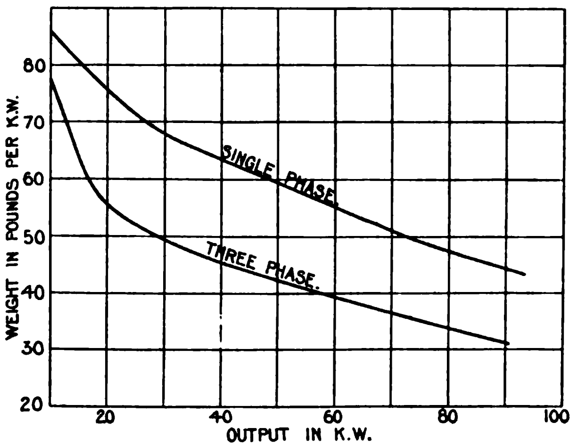
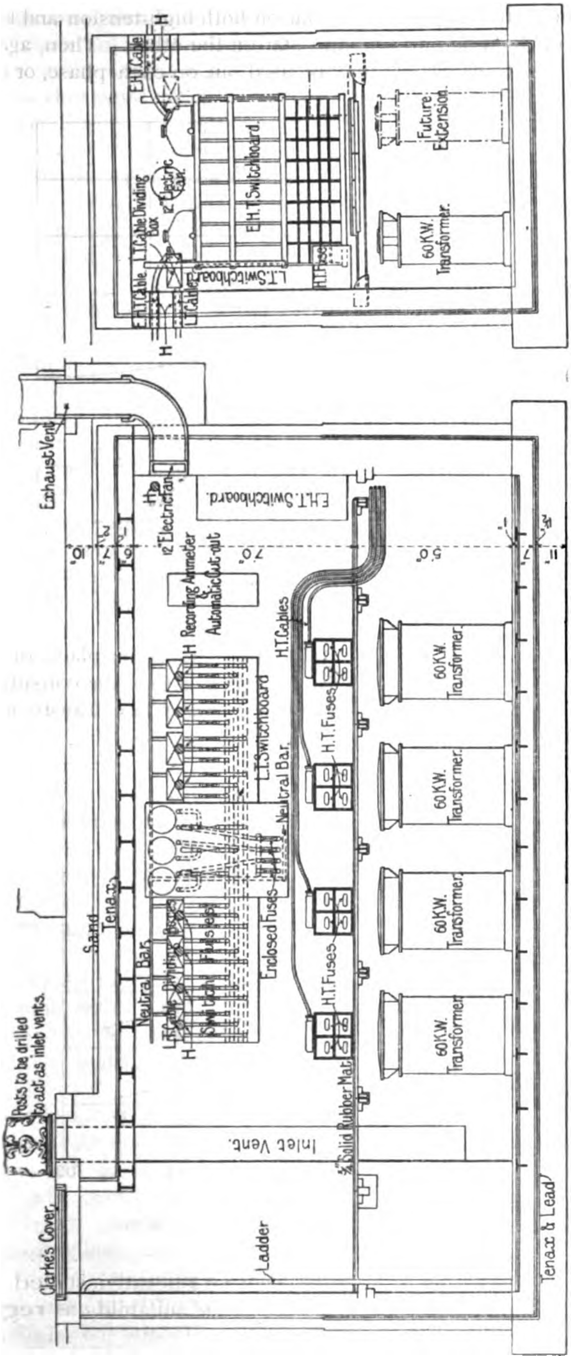


FIG. 5.—Transformers.

will generally be as follows: (1) capital cost per kilowatt installed; (2) weight per kilowatt installed; (3) efficiency; (4) suitability as regards working conditions.



H = Position of holes in wall for cable

FIG. 6.

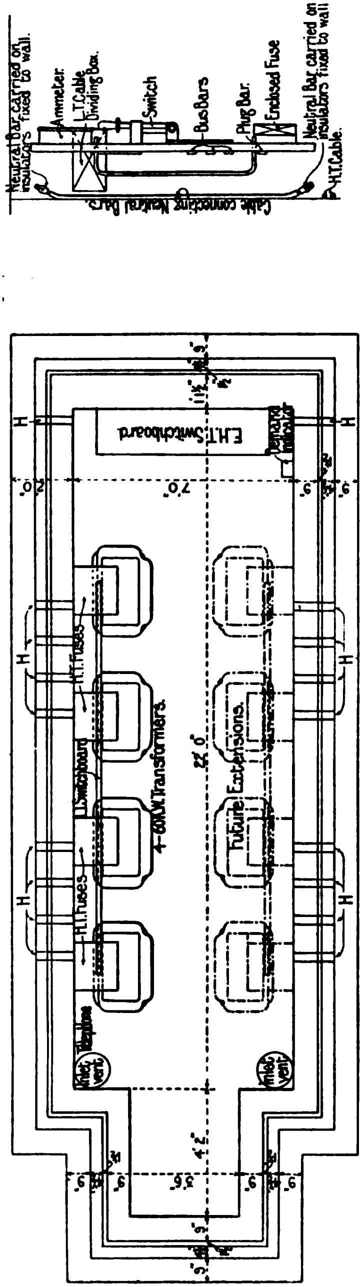


Fig. 6A.

As regards (1), the average cost of a three-phase transformer appears to be about 20 per cent. less than that of a single-phase transformer of the same output and type. On the other hand, a certain amount of spare plant will always have to be provided, and if three single-phase transformers be used, one spare transformer will act as an efficient spare to all three, whereas if three-phase transformers be used, it would in most cases be as economical to completely duplicate the plant as to multiply the number of transformers by using small ones of less efficiency and greater cost per kilowatt. The curve (Fig. 4) shows how rapidly the cost of transformers per kilowatt installed increases as the output is diminished. For instance, a 90 k.w. transformer would cost about 28s. per kilowatt, whereas three 30 k.w. transformers installed in place of it would cost 46s. per kilowatt.

As regards (2), where a number of sub-stations are distributed over a large area, the question of weight is of some importance as regards transport and appliances for moving the transformers in the sub-stations. The curves (Fig. 5) show that the three-phase has the advantage of the single-phase transformer in this respect.

As regards (3), the efficiency of the three-phase is usually less than that of the single-phase transformer. In good designs, however, this difference does not usually much exceed 1·5 per cent.

As regards (4), the three-phase transformer possesses

the advantage of equalising the pressure upon an unbalanced load. On the other hand, if a fault occurs in a transformer, three or more times the amount of plant is thrown out of use thereby than would be the case with a fault with single-phase transformers.

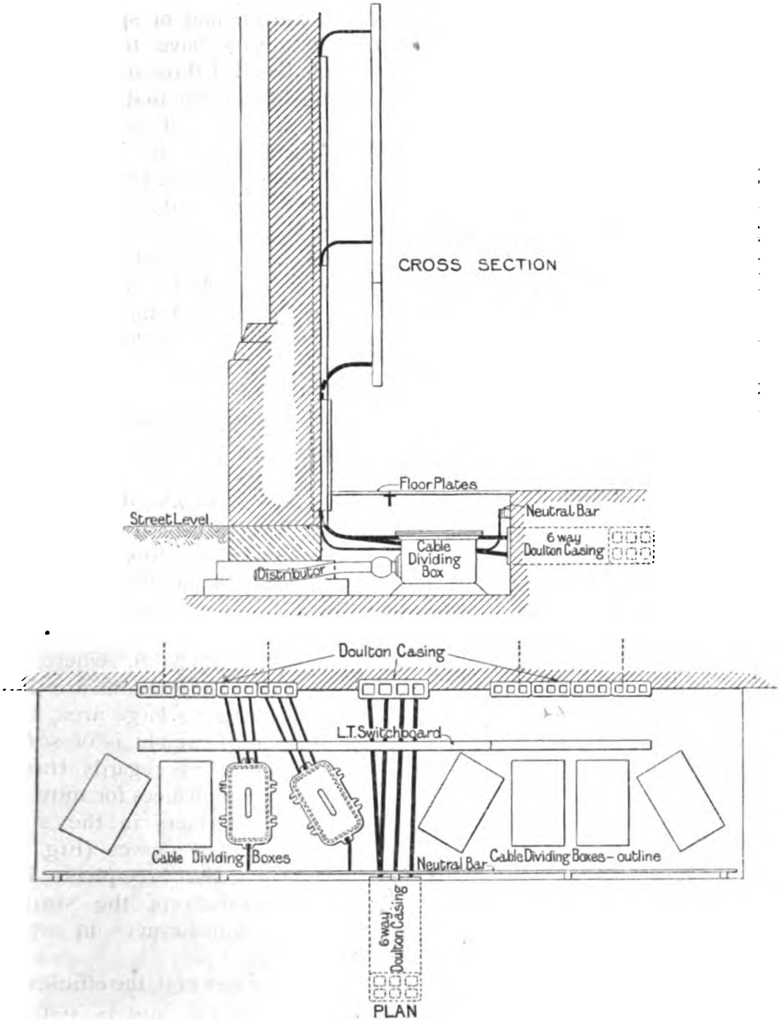


FIG. 7.

I might mention here that in Dublin we have not had the slightest difficulty as regards the banking of single-phase transformers in delta or star connection, transformers of 50 k.w. output sharing the load proportionately throughout the range with transformers of 250 k.w. output when banked with them, delta and star connected. A general

arrangement plan of a Dublin underground sub-station is shown in Fig. 6. The transformers in each of the 21 new three-phase sub-stations are of the oil-cooled type and British Westinghouse Company's manufacture. The results of tests of some of these transformers are given in Table III.

TABLE III.—Test of Oil Transformers, 50 ∾, Single-Phase.

Output of transformers in kilowatts	250	50	50	40	30	20
Ratio (volts)	5,000 / 2,000	5,000 / 2,000	5,000 / 200	5,000 / 200	5,000 / 200	5,000 / 200
Magnetising watts... ...	2,100	380	462	438	308	292
Copper watts	3,084	623	660	512	510	265
Total watts	5,184	1,003	1,122	950	818	557
Per cent. loss	2·08	2·0	2·24	2·37	2·73	2·78

The arrangement of the overground sub-station low-tension cables will be seen in Fig. 7. It will be noticed that the neutral wire from each cable-dividing box is joined to a copper earth-bar, which is connected through a recording ammeter to an earth-plate. This earth-

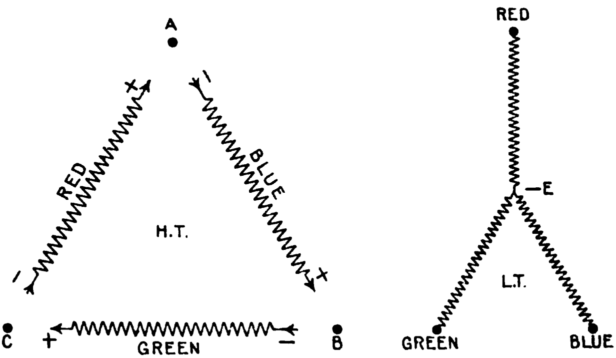


FIG. 8.

bar is situated in a cable trench in front of the low-tension board, where it is joined to three of the tails from the transformers star-connected and forms their neutral point. The remaining three transformer tails are connected through fuses and switches to three 'bus-bars indicated by colours, as the red, blue, and green phase respectively. Special attention has been paid to the arrangements for switching in a

spare transformer with ease and certainty as regards its phase relationship to the other transformers. The conditions to be satisfied will be evident from the diagram (Fig. 8). If A B C represent the high-tension 'bus-bars and + — the spare transformer terminals, the connection must be made in one of the three ways shown to correspond to one of the three phases on the low-tension side. The arrangements made for carrying out these connections in practice are shown in Fig. 9. In the centre of both high-tension and low-tension boards are placed plug connections of the well-known split-tube Ferranti type, actuated by a

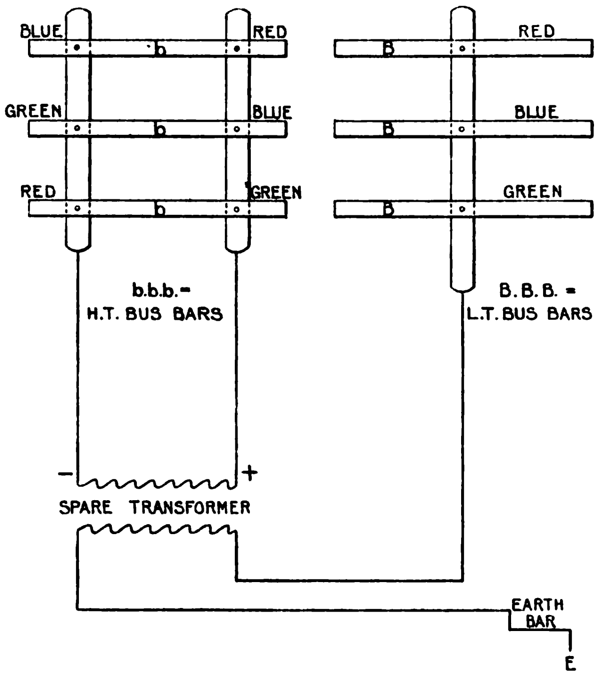


FIG. 9.

bayonet socket handle. All that is then necessary for the operator to do to replace a transformer, say, on the red low-tension phase is to insert plugs on the high-tension board in the two positions marked red, and the single plug on the low-tension board, making connection with the red phase and then close the switch.

Three-Phase Distribution.—In considering the relative merits of various classes of distributors we must take into consideration the following points :—

(*a*) As regards the consumer : (1) the maximum safe pressure permissible to earth and between the consumers' terminals and wires ; (2) the maximum permissible voltage and variation at the consumers' terminals ; (3) the minimum number of consumers affected by an interruption on any one conductor,

(*b*) As regards the supply company: (4) the maximum amount of energy capable of being transmitted for a given cost of cable; (5) the maximum pressure between any two conductors which the insulation of the cable and fittings of the street disconnecting boxes will have to withstand; (6) the maximum pressure to earth tending to break down the cable and disconnecting boxes.

As regards conditions (1) and (2), the Board of Trade regulations confine us within the limits of 250 volts between terminals and 4 per cent. variation either side of the declared pressure. It will be evident that conditions (1) and (4) are not the same in the case of three-wire distribution with direct or alternating current, and also in the case of multi-phase distribution, with cored cables, where the insulation of street boxes and that between the conductors of the distribution cables may have to withstand much greater pressures than will exist upon the consumers' premises. As regards condition (3), consideration should be given to the elasticity of any given system of distribution and the minimum number of consumers affected in the case of a temporary interruption of the supply on any one conductor of the distributor, such as would be caused by the blowing of a low-tension fuse or breakdown of a transformer in the case of three-phase distribution with four-core cables and network supplied from independent transformers star-connected. With three-phase distribution we have the choice between three-core or four-core distributors. We are also at liberty to vary the size of the fourth wire of the four-core cable.

Table IV. illustrates the principal points by which distribution by three-core and four-core cables would differ in practice. As regards the size of the fourth or neutral wire to be adopted, we might follow the practice of three-wire distribution and reduce the section of this to some extent. There are, however, reasons which probably justify retaining this conductor of the same size. For instance: (*a*) one phase being interrupted, the resultant full-load current of the other two phases will combine to form full-load current on a neutral of the same section as the other conductors, and one-third only of the consumers will be affected; (*b*) similarly, two phases being interrupted, the neutral will then act as a return for the third phase of equal section, with a slightly increased drop in pressure; (*c*) the increase in the total cost of the cable with the fourth core added of same section as the other three cores only amounts to 20·6 per cent. and 17 per cent. respectively in the case of the 0·1 and 0·05 distributors considered for 30 per cent. increase in copper.

The principal points in favour of the four-core cable system which has been adopted in Dublin are: (1) greater amount of energy transmitted for given capital cost, the system acting in a manner similar to an ordinary three-wire distribution; (2) less variation in pressure due to want of balance amongst consumers; (3) less inconvenience to consumers in the event of any phases being interrupted—our working experience in Dublin is that considerable weight should be attached to this point. On the other hand, against the four-core cable we have: (1) greater pressure between conductors, tending to break down the

insulation of the cable and street boxes; (2) extra expense as regards fittings in house service boxes, disconnecting boxes, etc.

TABLE IV.—Comparison of Four-Core and Three-Core Distributors with 200 Volts at Consumers' Terminals and C R Drop of 4 per cent. per Quarter Mile.

Description of Distributor.

Four-core. Consumers connected between each phase and neutral.		Three-core. Consumers connected between each phase and neutral.	
Section of each conductor in square inches.			
0·1	·05	0·1	0·08
Effective pressure between conductors in volts.			
346	346	200	200
Maximum instantaneous pressure between conductors.			
488	488	283	283
Effective pressure between conductors and neutral or earth.			
200	200	115·5	115·5
Maximum instantaneous pressure between any conductor and earth.			
283	283	163	163
Drop in volts per core per quarter-mile = 4 per cent. of consumers' pressure.			
8	8	4·6	4·6
Current density per core in amperes per square inch to give 4 per cent. drop.			
726	726	421	421
Number of kilowatts transmitted, with 4 per cent. drop per quarter-mile.			
43·5	21·7	14·6	7·3
Cost of cable in £ per quarter-mile laid and jointed in troughing.			
£181	£124	£150	£106
Capital outlay in £ per kilowatt transmitted quarter-mile.			
£4 17s.	£5·72	£10 3s.	£14 5s.

HARMONICS.

It is well known that if the neutral point of a star-wound generator be earthed and the generator coupled up to a cable system, harmonics of certain orders, if present in the pressure wave, will cause a current to flow between the neutral point and earth, the amount of this current depending upon the capacity of the cables and self-induction of the generator and load. Tests of the amount of the current passing between the neutral point of the Dublin generators and earth have been made on different occasions, and it has been found that this current is least at time of full load, and increases generally as the load falls off.

Measurements of the amount of this condenser current at Pigeon House gave the following results:—

	Amperes.
Week-day full load, two 1,000 K.W. Machines running ...	4·8
„ light load, one 500 K.W. Machine „ ...	6·7
3 Trunk Mains only „ „ „ ...	2·29
2 „ „ „ „ „ ...	2·09
1 „ „ „ „ „ ...	0·66

Early one Sunday morning the largest observed value of this current was obtained, and amounted to 15·8 amperes. At this time

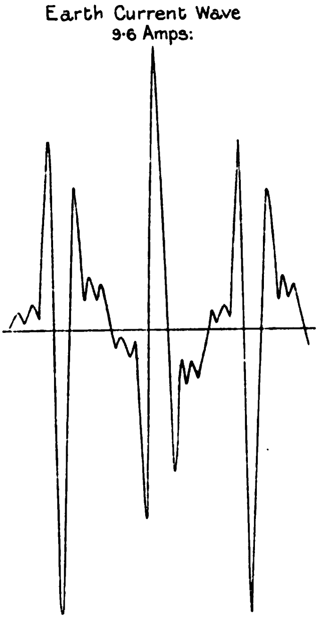


FIG. 10.

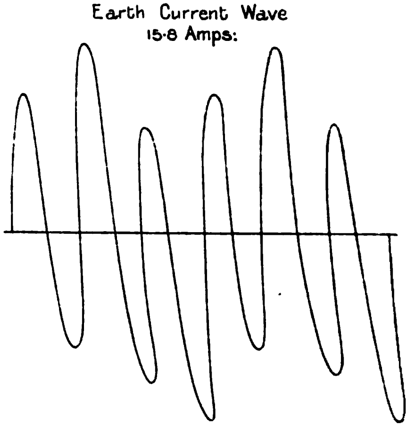


FIG. 11.

little more than the magnetising current to sub-stations was being sent out from the works.

In addition to the measurements of the current by a Siemens electrodynameter, attempts were made to ascertain the exact frequency of it:—1st, by means of a telephone; 2nd, by means of the oscillograph; and, finally, to recognise, if possible, the harmonics on the fundamental pressure waves producing the current between the neutral point and earth.

In making the first test a telephone in circuit with a flat exploring coil was alternately superposed on two solenoids, one connected to the ordinary lighting circuit at the works, and the other in circuit between the neutral point of the generators and earth.

A great difference in pitch was at once noticed, the pitch of the note produced by the lighting circuit corresponding very nearly to the second octave below the middle of an ordinary piano (50 ∾), whilst

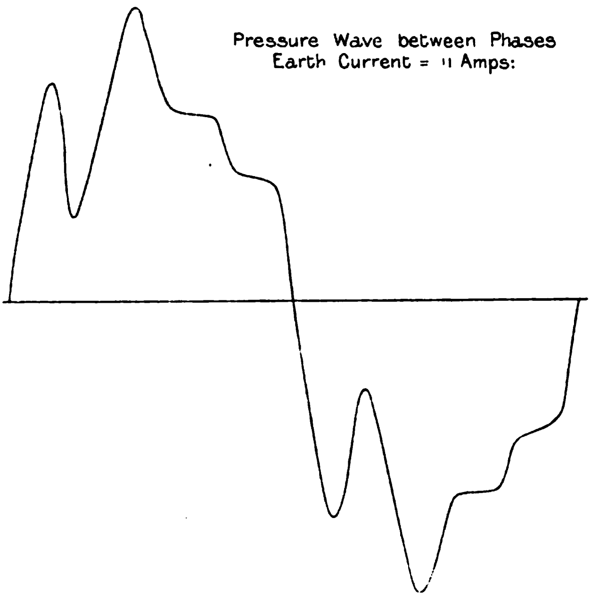


FIG. 12.

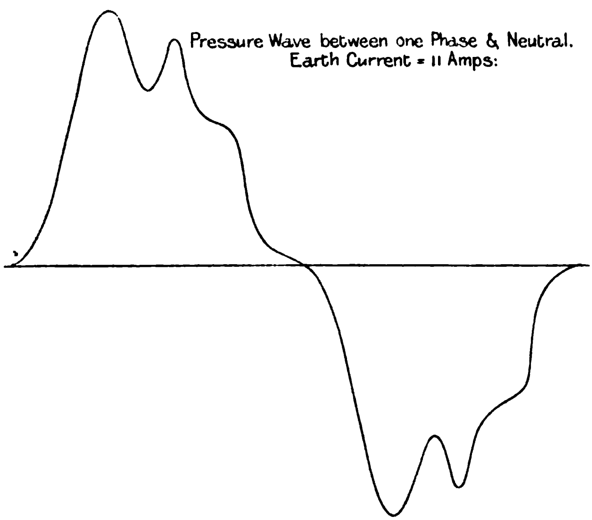


FIG. 13.

the current from the neutral to earth was over an octave higher (as far as could be judged, an octave and a major third or fourth).

In making the second test by means of the oscillograph, a rotating mirror was driven by a small motor at a fixed speed and the distances between successive waves compared :—

1st when the instrument was connected to the lighting circuit.
2nd ,, ,, ,, ,, earth ,,

These distances were usually found to be very nearly in the ratio of 1 to 3 as regards the fundamental waves (*Cp.* Figs. 10 and 13), but with light load and maximum earth current a powerful resonance of a 9th harmonic occurred in this circuit as shown by the oscillograms (*Cp.* Figs. 11 and 13).

The next point to be experimentally determined was whether the effect noticed was due to harmonics acting simultaneously from the neutral point to the conductors attached to each phase.

It will, of course, be evident that if such is the case the harmonics will be present in the pressure wave taken between the neutral point and any one phase, whilst they will be absent in the pressure wave taken between phases. The results of this test are given in the oscillograms, Figs. 12 and 13, which differ in shape, and apparently show that such harmonics existing in the machine windings are the cause of the earth current in the first place; this current under favourable conditions of self-induction and capacity is greatly magnified, bringing about almost pure resonance of a 9th harmonic at very light load.

In concluding these short notes, the writer desires to express his thanks to Mr. Robert Hammond for permission to bring the subject before you.

Professor Thrift.

Professor W. E. THRIFT (*Chairman*) asked Mr. Brew to what causes the idle currents in mesh-wound generators were usually attributed, as it had been suggested to him that they were liable to be set up by certain harmonics. With regard to the measurement of capacity-currents referred to by Mr. Brew, he thought there was an unaccountable discrepancy between the calculated and observed values, and he asked whether the actual leakage had been determined or not. In the course of some remarks on resonance, he noticed that the conditions seemed to favour resonance—*e.g.*, with the seventh harmonic. The banking of transformers was also a matter of great interest, and he was somewhat surprised at no difficulty having been experienced in the successful banking of different sizes.

Mr. Sheardown.

Mr. P. S. SHEARDOWN thought the reduction in exciting-current of the 500 k.w. generators at the Pigeon House Station on the insertion of 9 miles of 0·15 sq. in. three-core cable (Fig. 4 of Mr. Brew's paper) to be rather large. The exciting-current necessary to keep 5,000 volts at the terminals had to be reduced, in fact, from 89 to 78 amperes, a reduction of over 12 per cent. He (Mr. Sheardown) had had a test made on a 500-k.w. B.T.H. three-phase 2,500-volt alternator at the

Ringsend Station, the exciting-current, taken from 500-volt 'bus-bars, necessary to produce 2,600 volts on open circuit without any cable connected to the 'bus-bars being 14·5 amperes. On connecting up in parallel to the generator two triple-concentric cables each 0·05 sq. in. in section and connected in series with them a three-core cable of 0·1 sq. in. section, making in all 9·2 miles of cable, the exciting-current required to keep the pressure at 2,600 volts was reduced to 14 amperes, a difference of 3·4 per cent. The experiment was not, of course, on all fours with Mr. Brew's, as he was not quite certain of the capacity of the cables when connected up, but the triple-concentric cables in parallel would probably have a higher capacity than the Pigeon House three-core cable, and it appeared to him in any case, that the capacity would not account for the great difference between 3·4 and 12·2 per cent. Continuing, he questioned the correctness of the terms rotor and stator applied to a generator. Mr. Sheardown.

Mr. M. Ruddle said that he, in most cases, preferred three-phase transformers to single-phase ones, on account of their tendency to balance, which outweighed the advantages of the single-phase type named in the paper. No difficulty was ever experienced in getting banked transformers to share load equally, provided that they were suitably designed, but a very small thing—such, for instance, as a bad connection—might throw them out. As a matter of fact they did not share quite perfectly at all loads, and as proof of this he quoted the figures below, relating to two banked sets of three transformers of 250 k.w. and 50 k.w. output respectively at various loads:— Mr. Ruddle.

50 k.w. transformers	...	12	10	15 amps.
" "	...	22	21	26 "
250 k.w. transformers	...	50	42	45 "
" "	...	96	90	104 "

He mentioned that the slow pulsation or surging referred to in the paper caused very little trouble when the load was considerable, but with light loads, say after 11.30 p.m., it was quite in evidence. It has been got over in other places by inserting choking coils in the primary circuit.

Mr. W. Tatlow mentioned that Mr. Brew used the short-circuit currents to measure impedance, but that the impedance so obtained was not the same as the working impedance. He agreed with Mr. Brew, that the short-circuit current must lag and have a large armature reaction. But for this reason the short-circuit current might be reduced, and the deduced impedance would be too high. He thought the great advantage of four-core distribution to lie in the fact that it enabled a distribution at a higher pressure than the lighting pressure. But he objected to the great anxiety about balance which was sometimes evidenced by station engineers and the complications involved in splitting up small installations into different circuits. Mr. Tatlow.

Mr. W. Brew, in reply, said that the idle currents in mesh-wound generators were apparently due not only to certain harmonics set up by the stator slots, and referred to in his paper, but also to irregularities Mr. Brew.

Mr. Brew. in the winding, eccentricities in the rotor, and mechanical matters of that nature. Regarding leakage, he mentioned that apparatus which, when measured in the ordinary way, gave an infinite insulation resistance, was capable of passing a measurable leakage current at high-pressures due to brush discharge at numerous points in sub-station switch-gear, etc. As to resonance, it might be dangerous, but the oscillograph enabled them to recognise the harmonics, and to avoid the combination of circuits likely to give trouble. Banking of transformers in three-phase working was perfectly easy and merely a matter of design, but, just as in the single-phase working, differences in the design of the banked transformers might cause the load to be shared unequally, a very slight cause would sometimes affect the proportion in which the load was shared in the case of large transformers banked across the same 'bus-bars. A few spirals formed in the secondary leads of a transformer taking more than its share of the load under these conditions would sometimes remedy the trouble, the turns in the cable having a slight choking effect with large secondary currents. He thought the difference between the magnetising currents with various capacities found by Mr. Sheardown and those in the paper was probably due to a considerable difference in the design of the generators—*i.e.*, Oerlikon and Thomson-Houston machines.

MANCHESTER LOCAL SECTION.

THE STEAM TURBINE.

By William Chilton.

(*Abstract of a paper read at a Meeting of Section on February* 2, 1904.)

In principle the Steam Turbine is a machine for directly converting into rotary motion a portion of the kinetic energy of steam. There are two principal types of turbines: one, in which nearly the whole available energy of steam is used in an expanding nozzle to give to itself a very high velocity, before being utilised in giving rotary motion to a wheel; the other, in which the steam passes alternately through many rings of fixed guide blades and of revolving blades, and expands by a small amount during its passage through each ring, until it leaves the last row and is discharged into exhaust, having parted with the greater portion of its usable energy. The De Laval Turbine is of the first order, the Parsons of the second. The Rateau and the Curtis Turbines combine some of the features of both. All these turbines may be either of the parallel or of the radial flow type, but have mostly been developed on the former lines. The velocity attained by steam in the Parsons Turbine, compared with that in the De Laval Turbine, is low, as it depends on the small difference of pressure on the two sides of a ring of blades, and, as this pressure difference can be made very small, depending, as it does, on the number of rows of blades, it is possible to reduce the velocity of the steam, and therefore the speed of rotation of the wheel, to very manageable limits.

The Parsons Modern Steam Turbine is shown in section in Fig. 1. It consists primarily of the casing C, which carries the stationary guide blades S, and the rotor or spindle R, which carries the moving blades M. The rotor is carried by two main bearings B, B_1, which are the only portions of the turbine proper subject to mechanical friction. Fig. 2 shows the type of bearing used in the smaller turbines up to about 500 k.w. output. It is formed of a solid gun-metal bush B, in which the spindle of the rotor revolves. The bush is made with a solid collar at one end and a loose collar at the other. Between these collars and surrounding the bush are three tubes, T, T_1, T_2. Small clearances are allowed between the outside of the bush and the inside of the first tube and between the outside and inside surfaces of the tubes themselves. These small clearance spaces are arranged so that oil can be forced into them. A flexible bearing is thus obtained, which allows the rotating mass to take up its natural centre line of revolution, and the viscous friction of the oil in the clearance spaces helps to damp any vibration set up by small inaccuracies in balance. The lug L prevents the bush turning with the spindle.

In the larger sizes of turbine, where the speed of rotation is lower, an ordinary split bearing lined with white metal is used. The casing is divided into three main portions, which may, for convenience, be referred to as the high pressure, intermediate pressure, and low pressure cylinders. Each of these is again divided, as shown in Fig. 1, into two or more stages of increasing diameter. The stages, the cylinders, and also the areas of the passages through the blades, are proportioned so as to deal in an efficient manner with the steam as it passes through the turbine in its continuously expanding course from the steam inlet to the exhaust end. Steam enters through the regulating valve V into the circular chamber O. It first passes through a ring of fixed guide blades, which direct its path, so that on leaving them it glides on to the entrance sides of the moving blades absolutely without shock. The moving blades, again, are so fashioned that the steam will flow without shock into the entrance opening of the next row of fixed guide blades until it is discharged at the exhaust end after having been expanded down to the pressure of exhaust, and issues into the exhaust chamber E from the last row of moving blades without drop in pressure. The differences of pressure on the two sides of the moving blades already mentioned produce an end thrust in the rotor. To balance this end thrust there are three dummy pistons—D1, D2, D3—on the rotor; circumferential grooves are cut in these pistons, with which corresponding brass rings fixed to the casing engage. The sides of the grooves and of the rings are ground up face to face, so as to

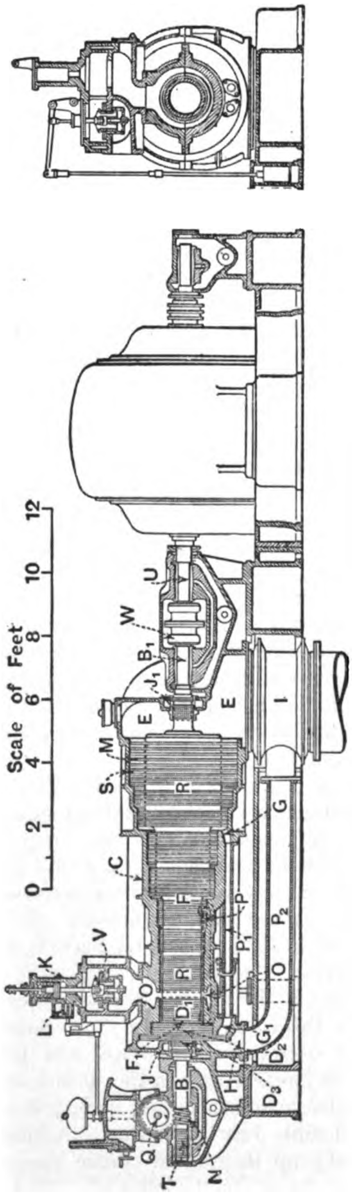


FIG. 1.—Section of Brush-Parsons Turbine.

prevent leakage of any but very small quantities of steam. The first and smallest balance piston balances the end pressure of the high pressure, the second that of the intermediate, and the third that of the low pressure cylinder. There are also the balancing passages, P, P_1, P_2, which equalise the pressure at FF_1, GG_1, HE. Passage P, balancing spaces F, F_1 is shown dotted. To keep the moving blades always in correct relative position to the guide blades, and also to take up any small unbalanced force, a thrust block is supplied shown at T on the diagram, and also in detail in Fig. 3. It is divided horizontally; the lower half is fixed, and the left-hand faces of the thrust collars on

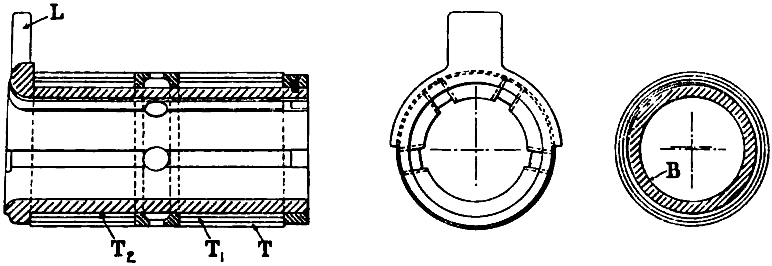


FIG. 2.—Parsons Flexible Bearing.

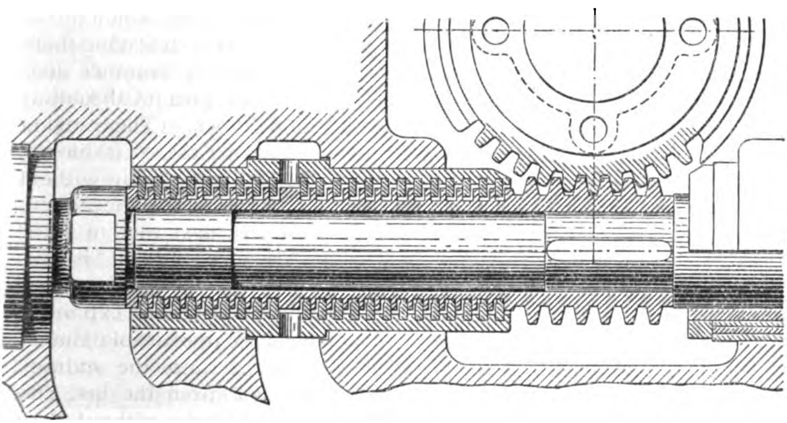


FIG. 3.—Thrust Block for Turbo.

the spindle bear against the right faces of this lower block; the upper block can be set to the left, so that the right-hand faces of the collars bear against the left faces of the upper block; the rotor is thus prevented from moving either way.

J, J_1, Fig. 1, are the spindle glands, which are made in the form of circular bushes in halves, with grooves on their inner surfaces, and collars turned on the spindles engage in these gooves. The spaces J, J_1 round the glands are, in the case of condensing turbines, supplied with a small quantity of low-pressure steam, and through holes in the

bushes this steam can find its way into the grooves, and from the grooves into the exhaust passages H and E. By this simple device air leakage into the spaces subject to vacuum is prevented. When the turbine is worked non-condensing, steam which may have a tendency to leak past the glands into the engine-room is drawn off through spaces J, J1 by means of a small ejector not shown on the drawing. The double-beat valve V is attached to the piston of a steam relay cylinder K, which is continuously supplied with a small amount of throttled steam on the underside of its piston. A strong spiral spring on the upper side of the piston tends to keep the valve down on its seat against the upward pressure of the steam on the underside of the piston. The small piston valve L of the steam relay controls the exhaust of the cylinder. When the relay opens to exhaust the steam under the piston is free to escape, and the spring can close the double-beat valve V. When the exhaust is throttled or closed by the piston valve L the steam pressure overcomes the push of the spring, and the valve is lifted. The relay piston valve L receives an intermittent reciprocating motion from a cam on the shaft Q. The position of the relay piston valve L in relation to its exhaust port passage is controlled by an ordinary centrifugal spring governor in such a way that at light loads and at no load the exhaust is more fully open than at the higher loads, and consequently the regulating valve V is open to steam for shorter periods at the lighter than at the heavier loads. At full and overload the valve is almost continuously full open. One advantage of the reciprocating motion given to the valve and gear is that the whole of the governing mechanism is always on the go, and is therefore ever ready to respond to even the slightest changes in the load. Although at first sight this gear may seem to be of the cut-off type, an examination of the curves of total water consumption show that these follow the Willans straight line law, which is the characteristic of throttle-governed engines. A second governor, exactly similar to the first, controls a second double-beat emergency valve, which only comes into play if, perchance, the main governor fails to act. The emergency valve can also be controlled by hand.

The throttled steam mentioned above, which works the steam relay cylinder, is used after exhaust from this cylinder to supply the glands J, J1 with the steam necessary to prevent air leakage into the vacuum chambers. The crank shaft Q is driven by the worm-reducing gear N. It drives, as well as the cam already mentioned, the two governors by means of bevil gears, and also the oil pump which supplies oil under pressure to the two main bearings of the turbine and also to those of the generator. As shown, there are only two bearings in the turbine which have to take the weight of the rotor, but these are not subject to the pounding stresses which the main bearings of reciprocating engines have to withstand. The weight of the rotor of a 1,000-k.w. turbine is about 6,300 lbs., and is distributed in the proportion of about 2,830 lbs. on the bearing at the steam end, and 3,470 lbs. on the other; this gives a pressure per square inch on the area of the bearing (taking the area as length by diameter) of 38·5 lbs. on the first and 46·5 on the second, or a mean of 42 lbs. The surface velocity of the journal

varies from about 1,950 to 2,350 feet per minute, or a mean of 2,150 feet. Multiplying mean surface speed per minute by mean pressure on bearings or 2,150 by 42, we get the figure 90,300. It is interesting to compare these figures with the corresponding ones obtained in high-speed reciprocating engine work; pressure per square inch on main bearings 160 lbs. surface speed 575 feet per minute. The product of these two figures is 92,000, or approximately the same as in the turbine. I is an expansion pipe joining the exhaust of the turbine to the condenser, and is made as flexible as possible, so that the cylinder shall not be distorted by its connection to the condenser or the exhaust pipe. U is the main bearing of the generator. The turbine spindle and generator spindle are joined by a flexible coupling enclosed in the box W. The method of securing the blades in the rotor and the cylinder is effective and cheap. The blades are drawn to the correct section from a special mixture of brass, or from copper, in lengths of 12 to 15 feet, and are cut to the required length. Grooves about $\frac{1}{4}$ inch deep are turned circumferentially on the outer surfaces of the rotor and on the

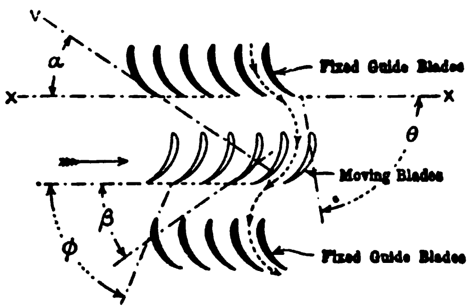


FIG. 4.—Passage of Steam through Parsons Turbine.

inner surfaces of the cylinder. The blades, after being cut to the correct length, are placed in the grooves in a radial direction. The width of the grooves is regulated, so that when the blades are in place they take up their correct angular position relatively to the axis of rotation. Caulking pieces of soft drawn brass and of a length equal to the depth of the grooves are placed in the grooves alternately with the blades; first a blade, then a caulking piece, and so on, until the row is complete. The caulking pieces are then tightly caulked home into the groove with special tools. When finished the whole forms a piece of sound work very well adapted to the function it has to perform.

In some recent correspondence in the Electrical papers much was said about the ripping out of the blades, due to the fouling of the blades against the cylinder walls, or to the blades being drawn out of the grooves by centrifugal force, or to the deleterious action of superheated steam on the metal. Blades have occasionally been ripped out, but accidents of this nature to the turbine are probably of less frequent occurrence than are accidents to reciprocating engines. There is, however, an important difference. Several rows of blades may be stripped from the cylinder or the rotor or from both, and no bad results

ensue; the attendant, in fact, may not even be aware of the accident the principal effect of which is a drop in the steam economy of the plant. The plant can still be run until such time as it can be shut down for repairs. But mishaps do sometimes happen to reciprocating engines, usually fraught with consequences more serious than the stripping of blades in a turbine plant. We look upon the reciprocating engine nevertheless as a reliable machine, and when steam-users become more familiar with the turbine, they will look upon it as a machine at least as safe, and in many cases more convenient, than the ordinary engine.

In all machines designed to abstract kinetic energy from a moving mass in an efficient way, it is most important that the mass should glide on to that portion of the machine, generally a rotating wheel, whose

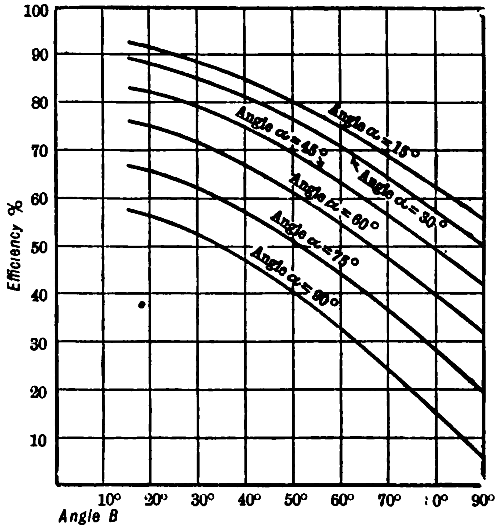


FIG. 5.—Blade Efficiency Curve.

V = Absolute Velocity of Steam.
W = Velocity of Blades.

$$W = \frac{V}{4}$$

function it is to absorb kinetic energy, absolutely without shock. That this may be so in the steam turbines we are considering, it is necessary to observe certain relations between the path of the steam and the angles of the blades, and also between the velocity of the steam and the speed of the blades. In Fig. 4, G, G1, represent two rings of fixed guide blades, M one ring of moving blades of a turbine. The arrow indicates the direction of motion of the moving blades. The line V represents the absolute velocity of the steam on leaving the guide blade G and the angle a indicates the direction into which the steam is guided by these blades in relation to the line XX parallel to the plane of rotation of the moving blades. θ the angle the side of the moving blade at entrance makes with XX and β the angle between the sides of the

moving blade at exit and the line XX. An important relation is that between the absolute velocity V of the steam before it enters the moving blades and the speed of the moving blades themselves. This latter is always a fraction of V, and, generally, the larger this fraction the higher the efficiency of the turbine. In practice the velocity of the moving blades is often one-half of the absolute velocity of the steam. The angle α, the absolute velocity of the steam and the speed of the blades having been fixed, the entrance angle θ of the moving blades must be formed so that the resultant path of the steam obtained by combining absolute velocity with speed of blades shall be parallel to the surface of the moving blades at entrance. The steam will now flow along and

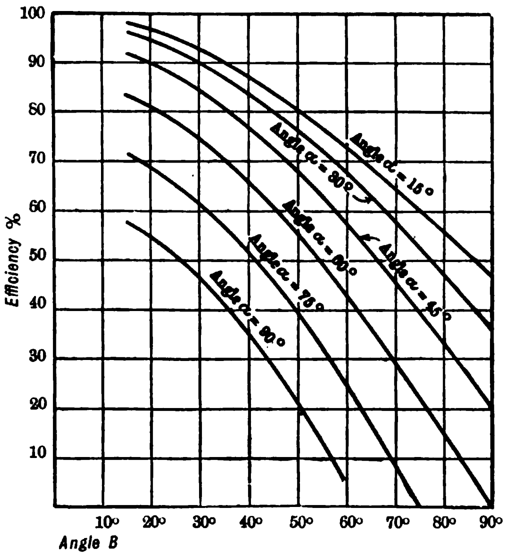


FIG. 6.—Blade Efficiency Curve.
V = Absolute Velocity of Steam.
W = Velocity of Blades.

$$W = \frac{V}{2}$$

parallel to the surface of the blade until it reaches the point of exit, making with the line XX the angle β. If free to choose this angle we shall naturally make it so as to give as high an efficiency as practicable. This angle, however, once fixed, the angle ϕ must be constructed so that the resultant path of the steam, obtained by combining the velocity of the steam at exit relatively to the blades with the speed of the blades, shall be parallel to the surface of the fixed guide blades at entrance. The shape of the curved portion of the blade between the inlet and outlet surfaces is not of much importance, provided it is smooth and takes the steam from one side to the other by a short and easy path.

The curves shown in Figs. 5 and 6 give the theoretical efficiencies, not taking into account losses due to friction, to be expected from turbine blades with different angles of entrance and of exit. The

vertical ordinates represent percentage efficiency, the horizontal represent the angle of exit β of the moving blade. Each curve is drawn on the assumption that the angle α is constant and the angle itself is marked on the curve, but the angle β varies from 15° to 90°. All the curves on Fig. 5 are drawn assuming the relation

$$\frac{\text{absolute vel. steam}}{\text{velocity blades}} = \frac{4}{1}, \text{ those on Fig. 6} = \frac{2}{1}.$$

It will be seen that there is a large range of choice in speeds and angles, but that, on the whole, $\frac{\text{vel. steam}}{\text{vel. blades}} = \frac{2}{1}$ is the best, although when this ratio is even $\frac{4}{1}$, by making careful choice angles, fairly good results may be expected.

We will now institute a comparison between the steam turbine and the reciprocating engine. With regard to turbines and reciprocating engines, at present there is room for both. For the smaller units and when working non-condensing the reciprocator has undoubtedly the advantage, but from 400 to 500 k.w. output and upwards, and when working condensing with a good vacuum that can be obtained at a small cost, the advantages are often on the side of the turbine. It is for the engineer to study each case on its merits, and then decide which plant he will use.

The author and the firm he represents—The Brush Electrical Engineering Company, Ltd.—hold no brief for either machine. They are designers and manufacturers of both, and can therefore impartially consider their respective merits. It may be well here to state that The Brush Electric Engineering Company, Ltd., have for some time taken up the manufacture of the Parsons Turbine under licence from Messrs. C. A. Parsons & Co.

TABLE I.

Vacuum in inches of Mercury.	0	25	26	27	28	29
Volume of 1 lb. of saturated steam in cubic feet.	26·36	145	177·6	237	347·6	709
Comparative volume — volume at 0 in. vacuum = 1.	1	5·52	6.75	9	13·3	27

It is a frequent complaint that comparisons of efficiencies are made between turbines working with very high and reciprocators with lower vacua. It is, however, well known that the steam efficiency of the ordinary steam engine only increases to a small extent when the vacuum rises beyond 25 inches of mercury, and this is more marked in high-speed than in low-speed engines. The reason is obvious, as a

consideration of Table I. will show. The volumes are here given of one pound of saturated steam at atmospheric pressure and also at vacua varying from 25 inches to 29 inches of mercury: in the top line are given the actual volumes in cubic feet; in the lower line, for the sake of more easy comparison, the volume at atmospheric pressure is given as unity; the others in multiples of unity.

The table shows how greatly the volumes increase with each inch drop in the absolute pressure beyond that due to 25 inches of mercury, and how great is the volume to be dealt with when the vacuum reaches 28 inches or 29 inches of mercury.

Now, it is not that reciprocating engines, as such, would not give better results at high vacua than at low, but because the low-pressure cylinder, valves, passages, aud exhaust pipes would have to be made of such inordinate sizes to deal with the enormous volumes at low pressures, that 25 inches vacuum is generally found to be about the economical limit. In high-speed reciprocating work, too, it is mostly

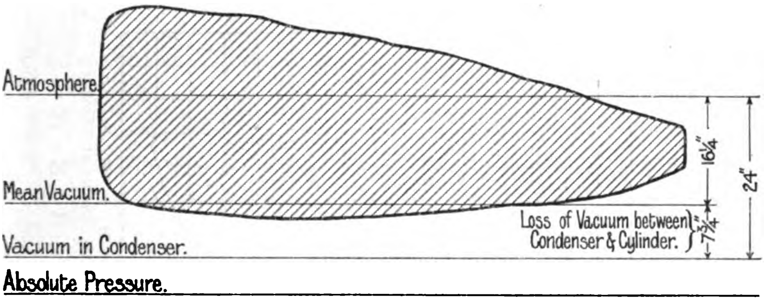


FIG. 7.—L.P. Diagram of 500 k.w. High-speed Engine.

Vacuum in Condenser	24 in.
„ „ Cylinder (Maximum)	19 in.
„ „ „ (Mean)	16¼ in.
Loss of Vacuum between Condenser and Cylinder ...	7¾ in.

found necessary to place the condenser at some distance from the engines. In turbine plant, on the other hand, it is convenient and also economical in first cost to place the condenser immediately below the turbine; the exhaust pipe is only a few feet in length, and can be from four to six times the area of that of a reciprocator of the same output; the drop in pressure between condenser and cylinder is in consequence very considerably less. Again, steam used in a turbine can easily be expanded 70 to 100 times, and delivered to exhaust at exhaust pressure, whereas in the reciprocator it is not convenient to expand much below atmospheric pressure, and there is often a large drop from the pressure at release to that of exhaust. In the turbine a drop in pressure between condenser and cylinder of half-inch, to three-quarter inch of mercury may be expected, but in reciprocating sets a difference of 5 inches between the mean back pressure in the cylinder and the absolute pressure in the condenser is quite common. It follows that in the turbine the gain in economy per inch increase of vacuum above 25 inches is much more than in the reciprocator, and for this reason it is

advantageous to incur the slight extra cost of condensing plant capable of giving the high vacuum necessary for high economy. The difference in vacuum in the condensers themselves, however, in the two cases, for the reasons already stated, is not so great.

If we require a mean vacuum during exhaust of 23 inches inside the L.P. cylinder of a high-speed engine it will be unwise to design the condenser to give less than 27 inches vacuum, whereas in a turbine set 27 inches to 27·5 inches vacuum could be expected in the cylinder with 28 inches vacuum in condenser. Fig. 7 shows the mean back pressure line in the L.P. cylinder of a triple expansion high-speed engine, the vacuum in the condenser is also given and the barometric pressure of 30 inches of mercury is assumed. The example is taken from a high-class high-speed engine of over 450 k.w. output, and of very recent date, and it will be seen that the loss referred to is in this case $7\frac{3}{4}$ inches.

Fig. 8 shows two curves giving approximately the saving which may be effected per each one inch increase of vacuum from 0 inches up to 28 inches vacuum. The upper curve gives the actual consumptions at

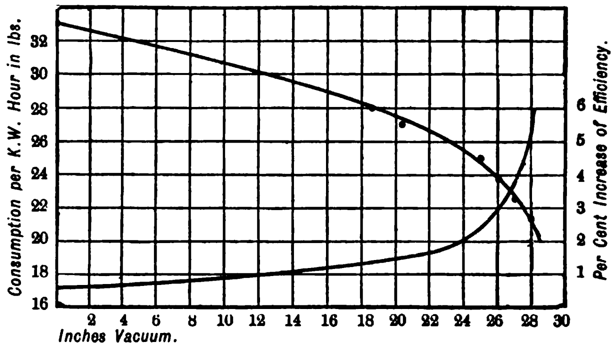


FIG. 8.—Gain in Steam Efficiency per each Inch Increase of Vacuum from 0 in. Vacuum to 28 in. Vacuum.

full load and the lower curve the percentage saving. The rapid rise of the lower curve well illustrates how much the turbine gains by working with a good vacuum. The dots on or near the curves show measured consumptions obtained at the vacua indicated below.

The following tabular comparison of the condensing plants required for reciprocating and turbine sets of 500 k.w. output working with saturated steam will be of interest:—

Particulars.	Reciprocator.	Turbine.
Consumption of Steam per k.w. hour, lbs.	24	22·5
Steam to be condensed per hour, lbs.	12,000	11,250
Tube Surface in square feet	1,050	1,540
Vacuum in Condenser, in. of Mercury	26·5	28
Air Pump cap., cubic feet per minute	125	150
B.H.P. to drive air-pump	3·3	3·85
Circulating Water, gallons per minute	730	830

Particulars.		Reciprocator.	Turbine.
B.H.P. to drive circulating pump	... ...	5·5 ...	6·3
Temperature circulating water inlet	... ...	65°F. ...	65°F.
" " " outlet	... ...	95°F. ...	90°F.
Mean Temperature in Condenser	... ...	119°F. ...	100°F.
Cost Prime Mover and Generator	... ...	£3,250 ...	£3,250
" Condensing plant	... ...	£556 ...	£659
Total Cost	... ...	£3,806 ...	£3,909

Extra cost of turbo plant over reciprocating plant about 2·7 per cent., but inasmuch as the engine will probably be fitted with an oil filter for extracting the oil from the exhaust steam, the cost of the turbo

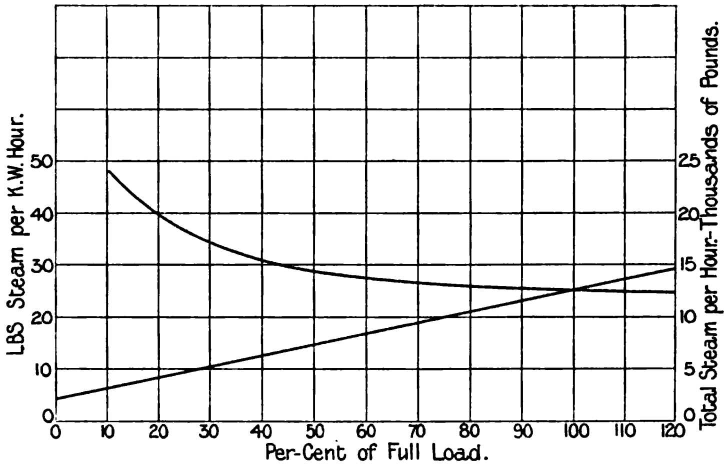


FIG. 9.—Tests of 500 k.w. Parsons Turbine at Cambridge.

plant will probably not be more than the other. The turbine requires no holding-down bolts, the foundations and buildings are less costly, and crane capacity required is less; add to this that no lubricating oil is necessary for cylinder lubrication, and the turbine comes out very favourably in comparison with the reciprocating engine.

With regard to superheat, both types of engines derive great benefit from its use, but for different reasons. One source of great loss in reciprocating engines using saturated steam is initial condensation, and this loss can be reduced by superheating. In the turbine there is little or no initial condensation, as the metal surfaces with which the steam comes into contact do not change in temperature on steady load. On the other hand, water, which may come over with the steam, in addition to that formed by condensation due to work done, produces in its passage through the turbine a large amount of viscous friction and reduces the mechanical efficiency. Superheating the steam reduces this loss. The advantage which each gains by superheating is about

the same, and the gain for each stage of 50° Fahr. of superheat is approximately as follows :—

First 50° of superheat ...	...	... 8	per cent.
Second „	„ ...	...	... 6	„
Third „	„ ...	...	... 5	„
Fourth „	„ ...	...	... 4	„

But the use of superheat introduces certain difficulties in both forms of generators, which however promise to be less in the turbine than in the reciprocator. In the former the clearances between the blade tips and the surfaces of the cylinder and the rotor have to be increased; in

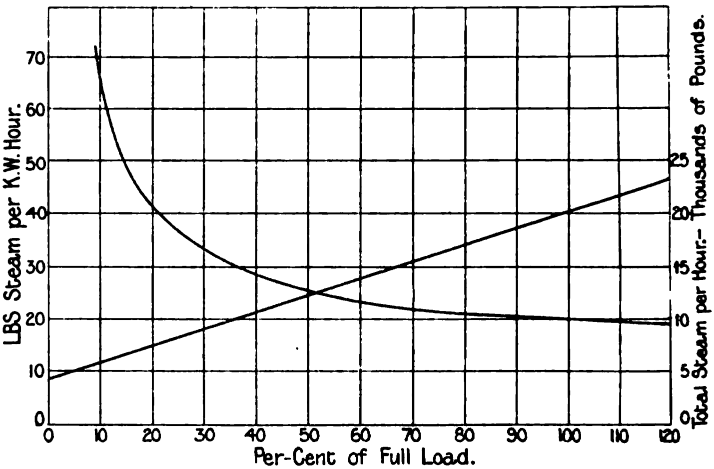


FIG. 10.—Tests of 1,000 k.w. Turbo-Alternator at Elberfeld.

the latter the valve and piston clearances. In the former there are no rubbing surfaces subject to the action of dry steam of high temperature, and no lubricant is used; in the latter a short run without the use of high-priced oil would play havoc with the engine. The curves in Fig. 11 show the increased efficiency to be expected by superheating the steam; the rising curve gives the percentage gain for various degrees of superheat on the consumption with no superheat, the falling curve gives the actual consumption in pounds per k.w. hour for various degrees of superheat. In Table II. are given the results obtained in the trials made by Professor Ewing at Cambridge, and it should be remembered that these turbines drive their own air and circulating pumps. The working pressure is 150 lbs. per square inch and the speed 2,700 revolutions per minute. These tabulated results are shewn graphically in Fig. 9, the straight line being total consumption of water per hour and the curve the water per k.w. hour at various loads.

TABLE II.

Test of 500 k.w. Parsons Turbine at Cambridge, driving its own air and circulating pumps, 2,700 r.p.m. 150 lbs. steam. No superheat.

Per cent. full load.	Steam Consumption.		Vac. in inches of Mercury.
	Lbs. per hr.	Lbs. per k.w. hr.	
117·2	14,320	24·4	27·9
104·0	12,970	25	27·8
54·5	7,730	28·3	28·2
32·1	5,320	33·1	28·3
0	1,850	—	28·3

Barometer 29·93 inches.

TABLE III.

Test of 1,000 k.w. Parsons Turbine at Elberfeld, driving its own air pump, 1,500 r.p.m. 135 lbs. steam. Mean superheat 25·7° F.

Per cent full load.	Steam Consumption.		Vacuum.
	Lbs. per hr.	Lbs. per k.w. hr.	
119	23,100	19·28	Average Vacuum in Condenser 27·5 inches.
99·5	19,800	20·1	
74·5	16,550	22·2	
50	12,300	25·4	
24·6	8,310	33·7	
0	4,050	—	

Barometer 30 inches.

In Table III. and Fig. 10 are given the results obtained at the official trial of the 1,250 k.w. plant supplied by Messrs. C. A. Parsons & Co. for

the Elberfeld Corporation. In this case the turbine drove its own air pump.

In the Cambridge trials the results were obtained without superheat, in the Elberfeld tests with the moderate superheat of 25° F. In Fig. 12

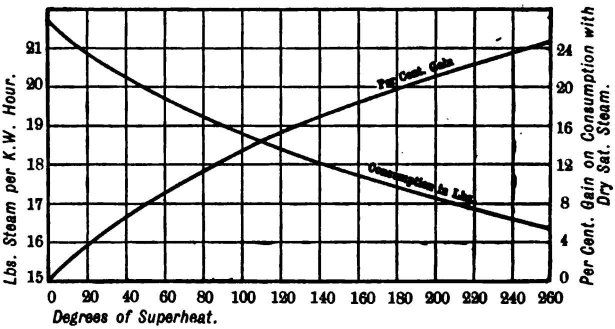


FIG. 11.—Curves showing Effect of Superheat.

TABLE IV.

Kilowatts output.	Weight of slow-speed engine	Ditto: weight of flywheel.	Weight of high speed engine.	Weight of turbine.
500	140	27	30	9
750	190	43	45	12
1,000	250	59	60	14
1,500	380	88	90	21
1,800	450	100	110	23
2,000	530	120	120	25
2,500	700	145	155	27
3,000	—	—	—	32
3,500	—	—	—	35
5,000	—	—	—	42

Comparative weights in tons.

are given the consumptions that can be guaranteed with steam of 150 pounds per square inch pressure and superheat of 50° F. and of 200° F. and vacuum of 28 inches of mercury.

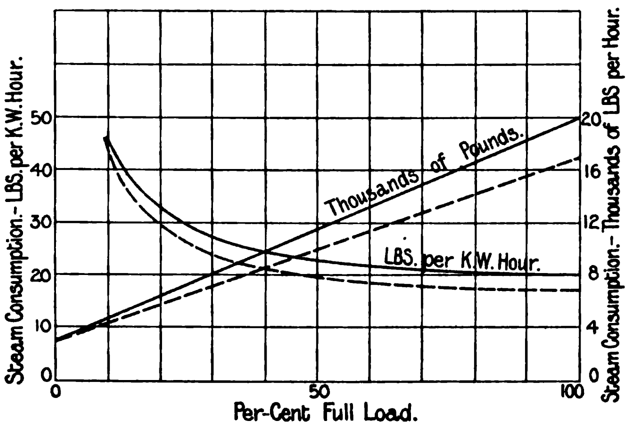


FIG. 12.—Guaranteed Consumption Curves for 1,000 k.w. Turbine.

Table IV. gives comparative weights of slow-speed engines, high-speed engines, and of turbines.

In conclusion, the author tenders his best thanks to Messrs. The Brush Electrical Engineering Company for the great help they have given him in the preparation of the diagrams, and to Messrs. C. A. Parsons & Co., and to Mr. J. H. Barker for the data and information with which they have supplied him.

GLASGOW LOCAL SECTION.

THE EDUCATION OF AN ELECTRICAL ENGINEER.

By Professor F. G. Baily, M.A., F.R.S.E., Member.

(*Abstract of a Paper read at meeting of Section, December 8th,* 1903.)

There have been in recent times several papers and discussions on the training of engineers, with comparisons between the systems in vogue in this and in other countries, but for the most part there has not been sufficient discrimination between the needs of electrical and of mechanical engineers, or else the papers have been prepared solely from the mechanical engineer's point of view.

To a large extent the training at the present day is the same as it was fifty years ago, a laborious apprenticeship in the workshops. One of the objects of this paper is to examine in what degree this can be modified to meet the requirements of electrical engineers, for to insist on the regulation apprenticeship in mechanical engineering, when a superstructure of electrical knowledge, both theoretical and practical, has yet to be added, results in many cases in a complete revolt, and we have a mixture of mechanical engineers ignorant of the principles of electricity, and electrical experts who are incompetent engineers.

Previous experience will not give us much help in this matter. To point to isolated cases of successful electrical engineers, one a converted mechanical engineer, another a converted pure physicist, is of little use, for when those men started there were no electrical engineers, and they learnt their work as the subject expanded. If they made mistakes, it was because the whole subject was in an experimental stage, and progress, though not perhaps slow, was certainly tentative. But the men we are training now will be called to a different set of conditions. Progress and change are as vigorous as ever, but mistakes are regarded as less excusable, and methods need to be less tentative. They must be prepared for novelty and change more revolutionary than any experienced in the mechanical branch, and scrutiny and criticism more firmly based than heretofore. We must educate for conditions, concerning which we have, at most, but the vaguest ideas. Confront, for example, an engineer of twenty years ago with an up-to-date polyphase tramway and lighting plant with its polyphase transformers, rotary converters, synchronous and induction motors, the troubles of synchronising, of phase swinging, of current rushes, of dielectric hysteresis and electrolysis, its substations with battery boosters, three-wire balancers, tramway boosters, and its appalling switchboards. He has grown up with them, but his earlier state of mind would be one of simple bewilderment. Not merely details, but the very principles are

novel, and his old theory would afford him no help at all in elucidating the *rationale* of the plant.

Therefore, while sound mechanical engineering is and will be an essential in every undertaking of engineering so far as we can see, there is no doubt that a training that fits a man for readily assimilating new methods is no less essential for all who wish to be in the vanguard of their profession; while even the rank and file will require some knowledge of the intangible entity which they desire to control. Recognising the utility of a knowledge of mechanical engineering, we must restrict its demands on the time of our student, and discover whether any or much change should be made in its range of subject, whether it should be learnt in a mechanical shop, or whether the special requirements of electrical engineering call for a training in definitely electrical establishments, or whether a combination of both is to be recommended.

We must recognise that there is a limit to the time that can be allowed for education, and also that education cannot be regarded as complete until the youth has a fair knowledge of the essential parts of all the work which he will be called upon to perform afterwards. It is not infrequently the custom for a lad to spend a full apprenticeship in mechanical engineering, and then to pick up his electrical engineering knowledge in his first place the best way he can. Or he will assume that his college course, if he has taken one, will constitute a sufficient electrical training. The latter course is not so bad as the former, and with a lad of ability may be safely followed; but his first year or so with the electrical firm is really a part of his education, and he probably gets paid accordingly.

There is more needed. Even a competent mechanical engineer might find a refractory dynamo beyond his powers, or might excusably tremble at the task of connecting-up a complete switchboard and cabling of an engine-room, or would make serious errors in the erection of a battery of accumulators, not to mention more complicated operations. There is much that needs to be learnt of a distinctive electrical engineering quality; and however necessary the mechanical training, the other part must be regarded as equally important. In my own experience I have found mistakes, carelessness, and slovenliness to be much more frequent in the electrical part of the work than in the mechanical details of the engine-room.

If what I have said be accepted, there will be no demur to the assumption that a proper course of instruction at some college should form an integral part of the educational scheme. We may begin with this, and examine its scope and place. College courses in engineering are things of modern invention, and even yet they are tacitly ignored in many places, or regarded with something of contempt or disappointment. And this contempt has been not undeserved in many cases. Often too much has been expected of them, and still more often the appliances and staff have been inadequate. The electrical engineering teaching is frequently even yet put into the hands of the professor of physics, or the professor of mechanical engineering, with perhaps an underpaid assistant who has turned his attention more or less to the

technical side. Out of the whole number of universities, university colleges, technical colleges, and technical schools, there are some twelve professors of electrical engineering, while there are about fifty institutions. In mechanical engineering or general engineering there are twice as many professors. Of chairs outside of technical colleges there are three professors of electrical engineering, one of which was created only this year, as against fourteen professors of mechanical or general engineering. All of these universities and colleges profess to teach electrical engineering, but a lecturer is considered sufficient for the purpose.

There is therefore very little inducement for a man of ability to devote himself to teaching. With all the talk about the need for the better education of engineers, nothing is being done to attract men to undertake it. And the equipment provided for teaching is very inadequate.

Turning to the instruction itself, it will not probably be denied that electrical engineering permits of more complete college training than does mechanical engineering, and that a thorough knowledge of theory and principles is more necessary. Calculations are more exact, and the problems admit, in consequence, of greater complexity of treatment. An engine, a turbine, a pump, or a boiler most people can understand fairly well; and though experimental difficulties are great, and data are in consequence imperfect, the calculations and knowledge obtainable concerning these machines are broadly simple, if the minutiæ are obscure. This is not the case in electrical work. There is an almost unlimited opportunity for precise calculation and prognostication, if the mental powers are sufficient. Therefore sound training is the more needed, and the electrical engineering course, at present too often a course of electricity with a little technical flavouring introduced here and there, should be among the most exhaustive and analytical in the whole college. But I do not wish to be taken to mean that the course should present, on a necessarily microscopic scale, the complete practical training of an electrical engineer. The teaching of evanescent details of current practice, the laboured use of empiric formulæ and practical tips, all these have no proper place in a college course. There is a temptation to introduce them, for they give the course an appearance of reality, and in so far as they incite the interest of the student they have their uses. But they are not the solid pudding, only the garnishing. Or, to change the metaphor, a course of pure electrical theory and technical tips is but the foundations of a building and the external ornaments. The real useful building has been omitted entirely.

What is required is a thorough analysis of the principles, with so much explanatory detail as will give a vivid mental picture, but all so constructed as to permit of a luminous and ready application to any particular piece of practice that the student may subsequently meet. So in the laboratory work the aim should be, not so much to teach special methods of testing in vogue in particular places, as to give a broad power in experimental work of all kinds, together with, of course, general skill in the choosing, arranging, and using of apparatus

for particular ends. One does not train a student to take his place immediately in some special testing department, but rather to enable him after a few days to pick up the work in any department, and to feel himself a master over, rather than a slave to, his experimental methods. Moreover, if these habits of criticism and independent thought are not roused in the student stage, before responsibility and limited authority exert a repressing effect, the mind is apt to degenerate into an attitude of timorous conventionality.

We come now to the question of apportionment of time. After a fairly long experience in teaching, I have no hesitation in saying that three sessions at college are not too much. Indeed, a poor student does not grasp the full course in three years, and a repetition of the third-year course will do him good. Still I am not sure but that even in that case such a student would be better in the works, for students of this type often grasp in actual practice what they have failed to understand from books or lectures.

As the scheme in the Appendix shows, the first year is taken up in teaching preliminaries and elements. In the second year a genuine beginning may be made on the principles of technical subjects, but it is quite impossible to deal with them in any wide spirit. It is principally occupied with the individual parts, apparatus, and machines, and the principles on which they work. In the third year a really strong course on dynamo machines of all kinds, on the theory of alternating currents, and on the general arrangements of plant may be assimilated, while the same standard is attained on the mechanical side. Some beginnings of original design in the drawing-office, some individual work in the laboratory, and some really good mathematical and physical work can be done. A good third-year course well assimilated lifts a man into a higher plane of thought and grasp of subject, while occupying only some seven months. They are some of the most important months of his life if he has ability.

When is this course to come? The half-time system, in which the apprentice or pupil gets away for certain hours of the day, is usually impracticable, in that it postulates a desirable technical college within easy reach of the works. With the present tendency to plant large works away from large towns this difficulty is obvious. And even if facilities are obtainable, I believe it is better to keep the mind on cognate subjects, and to work hard at them for long spells. Half-time means half energy and slow progress, than which nothing can be more wearisome. Let the college course in each year be continuous while it lasts, and absorb the whole attention of the student, but let there be a considerable gap in the summer for practical work.

Between the first and second years the time may profitably be spent in real earnest work in the college workshops. These are often derided, and sometimes the work done there is little more than amateur play. An endeavour to teach handicraft by a couple of hours' work here and there is not the best arrangement. Manual skill requires continuous practice, and steady work during the summer months is much more conducive to progress. Under the strict supervision and skilled guidance of the college instructors, with carefully designed

courses, the student readily acquires a fair skill in the use of tools, so that when he enters the works he will not blunder along, spoiling material, and the laughing-stock of his neighbour craftsmen. I count this time, not only as equivalent to shop work, but in the initial stage far superior.

The system I advocate is a modified sandwich system, which will relieve the works of the students until they are really capable of taking proper advantage of their opportunities there, and which will diminish the inconvenience of intermittent attendance. In the second summer some five months should be spent in the works—three in the pattern shop and two in the foundry. This is sufficient to give a grasp of the technicalities and principles of these shops. During this period the lads should be allowed, at stated hours, to visit other departments and inspect the operations going on in them. It is allowed in some shops, and the benefits accruing from it to an observing youth are marked. They would then return to college for their third session with a considerable idea of the construction and processes of manufacture of machines, and be far more capable of appreciating the courses of lectures of the third year, which are more distinctly technical.

At the beginning of the third summer they return to the works for uninterrupted work. They may spend five or six months in the machine-shop, and thus in three years they have completed their full college course, and have already learnt the processes by which machinery is made. Fitting, erecting, and the drawing-office follow in due course.

Before passing to these it may be well to say a word concerning the need for the previous courses and the time required. Actual skill in pattern-making, moulding, and turning, planing, or shaping, is not of much importance, since it is very unlikely that the young engineer will subsequently be called upon to execute work of this description at the speed required of the artisan. The last (machine work) may come useful; but with the time spent in the college shops, and another four or six months in the works' machine shop, he should be sufficiently competent for all ordinary small work. On the other hand, it may be argued that all of this is waste of time, but I think the knowledge of the processes of pattern making and moulding are highly desirable, and an intimate knowledge of machining processes even more so. Although great manual skill is not required, it is necessary that one should know how things are produced and what results are most easily produced. Nowhere else can so thorough a knowledge of machinery be obtained, and of the limits and capabilities of the workmen.

I am well aware that many successful electrical engineers have omitted this part of the training, and have known of the pattern shop, foundry, and machine shop only by casual experience. Therefore I do not profess to speak unhesitatingly on this point. While all will freely admit that these portions are desirable, they may not be a *sine quâ non*. But it will be noted that these portions are cleared off by the end of the third year. It might be permissible to omit pattern shop and foundry, and to place the machine shop in the summer vacation of the second year, and to begin the fitting shop immediately after

leaving college. The complete omission of the machine shop must, I am convinced, be detrimental; but by sharing eighteen months between the fitting and outside erecting, one year would be saved and very fair experience obtained.

These parts must obviously be taken in a shop which is well equipped in these departments, and therefore it is probable that a mechanical shop will in most cases be better than an electrical one. Of course, where the electrical and other work is so large and varied that it constitutes an important mechanical shop, every requirement is fulfilled, but I am strongly of opinion that a factory devoted exclusively to dynamo-, motor-, and transformer-making is of little use. The experience gained on the test plate should be obtained in a well-equipped laboratory, combined with occasional outside tests, in which the students would participate. The bobbin winding and insulating, the coil forming, sheet stamping and assembling, commutator building, and even the armature winding are not operations which are carried on outside of the factory, and an intimate knowledge of every screw and plate is not necessary. A dynamo, motor, or transformer is something which is bought in the solid, and comes usually in not more than three pieces. If it is damaged, in most cases the part is sent back for repair, and the replacement is very simple. If it works badly, in nine cases out of ten it is because it has been badly designed. There is far less of the numerous small accidents than can happen to a steam engine or boiler. It is not dismantled periodically for trueing up, except in obvious places. Therefore, I do not consider that exact experience in the manufacture of machines is an essential in the education of the majority of engineers.

In the scheme of education proposed I have allotted one year to outside erecting work, and this and the drawing-office work are the parts which should be essentially electrical. This will not exclude erection of boilers, engines, turbines, and smaller mechanical plant, nor experience with much machinery that may be driven by electric motors. As the erection generally includes the starting and preliminary running of plant, it has an educational value that can hardly be overestimated, and includes precisely that part of the education that cannot be obtained in any other way. Moreover these men should, under supervision of a foreman, form most efficient erectors, since they would at this stage of their education be well able to understand the principles and reasons involved, and would not be so liable to make absurd blunders as the more rule-of-thumb artisan.

It may be argued that a short period spent in a central station is productive of much valuable experience, and I am by no means inclined to dispute the matter. Many an erector and designer would be the better for a short experience of running the plant. He would appreciate better the importance of a number of small points, which the power-station engineer subsequently has to rectify; while it should be almost a necessity for a man in a consulting engineer's office. But it may perhaps be recommended as his first employment, rather than a part of his apprenticeship, for he could easily get a berth as switchboard hand or assistant engineer at a modest salary, especially after his work of erecting.

Before leaving the subject of shops in general, we may ask whether it is better to stay in one shop and be known by its name, or to take a year in a variety of places, as is recommended by a certain school of electrical engineering. There is much to be said on both sides, but it must be remembered that a change to a new place means loss of time in shaking down to the new conditions. While a single change may not be undesirable, too much of it seems risky; and it involves considerably more trouble to the masters. The system would, I believe, result in a succession of beginnings at elementary work, instead of a rise to fairly responsible employment, and I think the arrangement would be quite unworkable on a large scale.

It has often been argued that the works' training should precede the college training, on the ground that the training of hand is more easily learnt when young, and that the older student is capable of better work at college. To this I would say that it is not so much training of hand that is required as comprehensive grasp of shop practice—a far more difficult matter. We are training masters, not men. Secondly, by the sandwich course the manual training is begun in the first year, so that the initial handiness is obtained early in the course. And, lastly, I do not find that the older men have any great, I could almost say any appreciable, pull over the younger ones in the college course. The top men that I have are not often those who have passed through the shops. They have dropped out of the way of learning, and frequently do not make the progress that one would expect. Whereas, the gain to the student in the shops of understanding what he and others are doing is so patent that no proof need be adduced.

On the other hand, it will be found that certain lads of a fairly practical turn of mind, but with little power of assimilating knowledge from books or lectures, often do quite good work at college after their apprenticeship, while they derive little benefit from the courses if taken before the apprenticeship. A certain amount of discrimination is, therefore, advisable at the start, when this is possible.

To those who hanker after the long years in the shops, who insist that only an intimate acquaintance with the manufacture of engines and the working of machinery can produce a satisfactory engineer, I would point out that there is no such insistence on experience in a boiler works. Many of us have put down boilers, have used boilers, and repaired boilers, with no more knowledge of their manufacture than is derived from an occasional visit to a boiler works, and experience from the actual boilers with which we have had to deal. And the same applies to steam piping. In other words, we have learnt about boilers and pipes by erecting them and running them; and I believe the same will apply, partially at all events, to engines and other things. Therefore I lay very great stress on the outside erecting work, provided that sufficient knowledge has already been acquired to permit of intelligent appreciation.

And nothing will teach better that handiness and resourcefulness of which the engineer, beyond other men, requires a full measure. Moreover, there is an atmosphere of finality and responsibility about the outside work which cannot be realised so fully in the shop. And

there are the hard facts of the circumstances of the case—time, weather, buildings, immobility of set concrete, the working-in with other workmen, and other contracts—which constitute a large part of the troubles of an engineer.

Of drawing offices I fear to speak, for my knowledge of them is but scanty. But the work itself is certainly educational, and I could almost call it a moral education. Nothing requires greater definition of ideas than the reduction of them to a detailed working drawing. And an engineer is nothing if not definite. He is worse, he is dangerous. Of the exquisite skill attained by some draughtsmen, I can only say that it appears misdirected energy. The skill of the erector, of the fitter, machinist, moulder, smith, and even pattern-maker, are all evident in the finished article; but of the draughtsman, nothing. Therefore for our young engineer, draughtsmanship and the drawing office should be a means rather than an end. Moreover, while it is easy to get into a drawing-office occupation, it is frequently difficult to get out of it again into the fuller life of the executive engineer.

This brings the end of the scheme. It is clear that there are many things yet to be learnt, and I may mention a list of subjects, some of which will probably be omitted from the course. With the manufacture of dynamos and motors I have already dealt, and lest manufacturers be up in arms against the apparent slight to their difficult industry, I should add that a very fair knowledge of the construction will be gained from examples in various stages of completion and drawings in the college laboratories, and from visits to works—not by mixed hordes of all sorts of students, but by a small number of advanced students and past students.

The use and care of dynamos and motors, and a knowledge of their various idiosyncracies will form part of the laboratory course, and the erecting time will give further experience. But in this important part of knowledge—the running of engines, boilers, dynamos, etc.—very little is learnt in any apprenticeship, and a short experience in a power station is therefore to be desired.

The processes of manufacture of switchboards and of cables are specialised lines, detailed knowledge of which is probably of little value. They are bought in the block. But the erection and laying of them can only be learnt on outside jobs, and the working of them on the completed plant. House wiring may or may not be included. Its chief difficulties are architectural rather than engineering, and as the subject becomes more developed, engineers proper will have less and less to do with it. It will become a trade like plumbing, decorating, and joinery.

The special applications of electricity—traction applications to machinery, metallurgical and chemical work—cannot form part of a general course; and a training as above described will form a satisfactory groundwork, to which special knowledge can be added as circumstances dictate.

As a crown, a final touch to the educational structure, I wish to propose a sort of grand tour, such as our ancestors used to make for the completion of a gentleman's education. Without spending a year,

as they did, some two or three months, or more if possible, in this country, on the Continent, and in America, can be most profitably spent in investigating engineering work of all kinds. After the somewhat specialised work in one or two workshops, such a tour of inspection would exert a broadening influence unattainable by years of staying at home. Possibly the student is rather young, but if it is not carried out at this time there is little likelihood of a chance occurring again, nor of his having the money for its accomplishment. At the end of his course a holiday is due to him, and the parental purse is probably still available. For a party of four or five earnest young fellows nothing more interesting or more beneficial can be imagined than such an excursion, and with suitable credentials I believe much would be readily opened to them.

A few words on teachers and examinations may be in place in this discussion. In the early part of the paper the requisites of a college course were discussed, and the question arises—what sort of teacher is required? The ideal is easily specified. Wide experience in teaching and great powers of imparting knowledge are obvious requirements. No matter how learned, how brilliant a man may be, if he cannot teach he is not a teacher. Power of organisation likewise becomes of no small importance when departments grow large. Oratory and brilliance in set lectures are perhaps not necessary, and too much of these qualities is apt to be seductive and dangerous. A thorough and indeed profound knowledge of physical and mechanical science may be included in the ideal, though possibly profundity will not be obtained except in certain narrow lines; and the same standard is required in knowledge of the principles and practice of electrical and mechanical engineering. Likewise he should be skilled in experimental and laboratory work, able to initiate and to carry out research. Lastly, he should have that intimate knowledge of current practice and close connection with the engineering profession that can only be obtained by practising himself.

It is obvious that no one man can rise to this. In part he must trust to a certain extent in others. And I am inclined to put the last item, that of being an engineer in practice, as of less importance than some of the others, though that he should have had practice, and a good deal of it, is really necessary. A teacher of engineering who has derived all his knowledge from books should be ruled out absolutely.

A certain amount of practice, of the expert nature rather than the carrying out of large work, will probably be found desirable for the chief, but he should be allowed to obtain assistance in special lines from other engineers. Work should be shared, and additional professors or pro-professors, giving perhaps a single course of lectures on their special subject, should be included in the staff. At the technical school in Berlin, for example, I found five professors of electrical engineering, at least two professors of physics, and one of electro-chemistry. In a large town it should not be difficult to find help of an expert nature.

It should be mentioned that in the new University of Liverpool a faculty of engineering has been formed; and in mechanical, electrical, and civil engineering this method has been adopted by Professor Hele

Shaw. In a small way we do the same at the Heriot-Watt College, and we hope to extend the principle in time. Some other colleges have likewise adopted this principle, but only to a small extent. Much more use should be made of the expert knowledge of other men for the advanced classes.

Evening classes.—In this discussion on education no mention has been made of the opportunities afforded by evening classes. This omission is not because I am unaware of their existence. A large part of my work for the last eight years has been devoted to technical evening classes, and if one may judge by numerical results the work has succeeded in its way. But my own opinion of the results is that they are distinctly unsatisfactory. That the classes are better than nothing is obvious, but they have their limitations. Their benefit to the artisan I shall not enter upon, since the education of the artisan lies outside of the scope of this paper, and it will be sufficient to say that this part of the work is well worth doing. But the idea that a lad can pick up at the fag end of his day an education that will enable him to compete with one who has devoted three years to a sound scientific and technical education, is quite mistaken. In the elementary work all goes well, but there is a total breakdown when the subject becomes really difficult. Time does not allow of a sufficient training in mathematics, while chemistry, thermo-dynamics, and mechanics are wholly omitted. One can teach them facts, tips, pictures, but not principles or powers of analysis and deduction. There are brilliant exceptions of course, but in point of fact almost all of my satisfactory students in advanced work are old day students or old college students from other places. For these men, students previously trained in day classes, specialised courses in the evening are highly desirable. But the ordinary evening class training for apprentices and pupils is but a delusive inducement to omit the more thorough course, and it should be clearly recognised as a cheap and inferior class of education, only to be adopted by pressure of pecuniary circumstances.

Examinations.—A feature of modern engineering education is the examination, with its resultant certificate. Of late years examinations of all sorts have been somewhat discredited, but frequently without sufficient discrimination between different types of examination. It is comparatively easy to examine a batch of a score of men on the work they have been doing, and to tell with considerable accuracy the conditions of their respective minds. But when this is enlarged to several hundreds, trained in all sorts of ways and in different places, the examination paper requires to be of so general a character that cramming for it becomes fairly easy. And facility in examinations is an art, to be learnt by practice, and often possessed in great perfection by people who are not necessarily gifted to the extent indicated by their prowess in the examination lists. This is in high degree the case in an engineering subject, and the results of large elementary examinations must be considered only as possessing a very restricted meaning. But if we are to have public examinations, it appears to me that they should be organised on a wider basis than is at present the case. The City and Guilds of London hold certain examinations yearly for their own and

other students, and the system has grown so large that they are now in the position of a public examining body. But the papers are set, if one may judge from internal evidence, in great part on the particular courses which have been held at the Institute in question. While this is natural and desirable from the point of view of the Institute, it places all other students at a disadvantage. With the semi-official position which public opinion gives to the examinations, this is an injustice which should be remedied, and I trust that the recent creation of a technical side in the Education Department will result in placing this question on a more satisfactory basis.

One other question I may allow myself to mention. I refer to the relations between universities and technical colleges in regard to technical education. It is obvious that the technical college has a claim to the field of technical instruction. There lies its only reason for existence. But does the university do well to extend its work over the same field? In the same city, what is the advantage of competing establishments—competing for students, competing for private donations, and for municipal and government grants? It is a question which Glasgow, Manchester, and Birmingham will find troublesome before very long.

On my own part I see and have experienced objections, intrinsic objections, to the inclusion of the subject into the university curriculum. University methods and constitutions are, in the older establishments at all events, not well adapted to so rapidly changing a subject as electrical engineering. Nor is the instruction given in subsidiary subjects, such as mathematics, mechanics, physics, and chemistry, of a nature suitable for engineers. The classes intended for students studying these individual subjects for themselves are usually too comprehensive, too much devoted to academic thoroughness and attention to exhaustive consistency, and therefore much time is spent on matter which will be useless to the engineer. For their respective purposes they are well suited, but for the engineering course special lectures and even special lecturers require to be appointed. This being the case, there is no economy in the combination of the two. A properly equipped technical college in a large town should be of sufficient size to enable it to stand by itself, and not to require the ægis of the university—as witness the colleges in Germany. Its staff would be complete and of good standing. And with this improved status the quality of the staff would be improved.

In my own town of Edinburgh a *modus vivendi* has been adopted between the technical college and the university with harmonious relations and moderately satisfactory arrangements, but it is an accidental arrangement with no consistency; an amalgamation of existing interests rather than a scheme of original design.

Liverpool University has solved the problem by omitting the technical college and making the university assume the double *rôle*. As a self-contained institution, with no encumbering legacies, she may quite possibly prove this to be a successful plan, but the technical side in such an amalgamation needs to be strong and fairly independent, if it is to compete educationally with the technical college proper.

Something of co-ordination, of system, of recognition of bounds, duties, and claims is certainly needed. When the nation begins to recognise that haphazard growth is not the most efficient nor the most economical, something may perhaps be accomplished.

APPENDIX.

Outline Scheme of Education of Full Length.

Age at Start, 16 to 17.

First Year.—Six months' session at college, with courses on mathematics, physics, chemistry, mechanics, mechanical and hand drawing, laboratory practice, elementary mechanical engineering.

Four or five months' instruction in handicraft in wood and metal, carried out in college workshops specially arranged for instruction.

Second Year.—Six months' session at college, with courses on mathematics, physics, mechanics, general principles and important types of machines and methods in electrical and mechanical engineering, with machine drawing and laboratory practice in the electrical and mechanical engineering laboratories.

Five months' work in a factory with a complete mechanical engineering department, in the pattern shop and foundry, with liberty to inspect work in other departments at stated times.

Third Year.—Seven months' session at college, with courses in mathematics, advanced electricity, thermodynamics, etc., advanced electrical and mechanical engineering, machine drawing and design, laboratory work on electrical machines, prime movers, and testing of materials.

Five months' work in the factory in the machine shop.

Fourth Year.—Spent in the fitting shop.

Fifth Year.—Spent mainly on outside erecting work.

Sixth Year.—Spent in the drawing office.

Age at Finish, 22 to 23.

The fifth and sixth years should be spent in electrical engineering establishments, but the previous work can be carried out equally well in a mechanical workshop.

Professor Magnus Maclean said that his experience of evening classes during the past four years did not bear out the opinions given in the paper, as he had had some very successful students in them. His students in Glasgow were quite independent of the City and Guilds examinations, and he advocated the examination of students in their own college. The chief difficulty in this country was that manufacturers would not attach sufficient value to a scientific training. Professor Maclean.

Mr. W. W. Lackie deprecated the closing of technical colleges for half the year, for with a nine or ten months' session the three years' course could be got through in two years. He considered that electrical students should serve their apprenticeship with an electrical engineer. Mr. Lackie.

Mr. Hird.

Mr. W. B. HIRD, while approving of the scheme, thought that more prominence should have been given to the importance of scientific principles, and that the college work should deal with the application of scientific principles to practical work rather than with the teaching of engineering practice. He considered that at present the intimate relation between broad principles and practical applications was not properly taught. He believed it inadvisable to lay down detailed schemes of the requirements of college students when they entered the shops, as manufacturers could not be expected to modify and organise their workshops for their benefit unless a premium were paid, and he considered the system of premium pupils unsatisfactory to both parties.

Mr. Morton.

Mr. A. H. MORTON did not agree with the view that the giving of technical tips in college lectures was undesirable, as he had himself derived much benefit from this practice; and he thought that teachers of technical subjects should keep themselves well instructed in current practice for this purpose. He spoke of the advantages he had derived from evening classes, and refused to accept the condemnation that had been passed upon them.

Professor Jamieson.

Professor ANDREW JAMIESON approved generally of the scheme of education, and pointed out that it was very similar to that instituted by him at the Glasgow College of Science and Arts in 1880. He considered, however, that the total cost for the five or six years would be some £400 to £600. He disapproved of much changing from one shop to another, but recommended a mechanical shop for the first part, finishing with an electrical contractor. The early work in the college workshops and laboratories taught care in the handling of apparatus, in which respect the shop-trained student was apt to be deficient. He considered that the real test of the training lay in the appointments obtained by the students, and affirmed that he knew of no instance of a B.Sc. in engineering from a Scotch University holding a good post in an electrical or mechanical works, except he had personal influence. His experience with evening classes was that the works-trained men were superior to graduates from the Universities, and were now in better positions.

Mr. Pickstone.

Mr. M. T. PICKSTONE brought forward the proposal formulated by the North-East Coast Society of Engineers, whereby the more capable of the apprentices could obtain a college training. He proposed to adopt such a system in his own works (Bruce Peebles & Co.). Dividing the works into several departments, the young apprentice would start in one of them, and his progress would be carefully gauged. If satisfactory, he would pass at the end of the year to the next department, and so to the third. In the fourth year he is given a session at the technical college in the winter, and again in the fifth and sixth years, while evening classes have been attended in the earlier years. He proposed to pay the fees for the students, and in return they would be bound over to stay a certain time with the firm after the conclusion of the course. Thus a lad of good ability would have full opportunity for obtaining a first-rate technical education at little or no cost to his parents, while the firm would gain the advantage of a well-trained

staff, and would attract to itself the best brains in the neighbourhood. Mr. Pickstone.

Mr. H. A. MAVOR said that from his point of view, with all due respect to Professor Baily, he thought this paper was founded on a wrong conception, in so far as it did not distinguish between an engineer and an artisan. The question approached in the paper was how to make a manager of an electrical enterprise. In his opinion this could only be accomplished by letting the student study such an enterprise right to the bottom. The college had its place, and the workshop also had its place; the former grounded the student in scientific principles, and the latter familiarised him with materials and implements. He was strongly of opinion that, wherever the college sought to interfere with the workshop, it went out of its proper sphere and damaged its influence. He was sure that no manufacturer would employ a student direct from the technical college in preference to the youth who had gone through a thorough workshop training, with the early morning and other hardships described by Professor Jamieson. The college is only an incident in the career of the electrician, and by far the largest percentage of that career is outside the college altogether. Professor Barr was fond of reminding them that the men who had done most for the engineering profession were men who had had no real engineering training at all, but, however that might be, he (the speaker) was sure that if a young man's college training kept him ont of the workshop till he was over twenty years of age it did him an injury, as few men were able to learn to manipulate tools after that age. He thought that the earlier the budding electrician was drafted into the workshop the better. Mr. Mavor.

Mr. J. B. HENDERSON considered that manual training should be taught at school rather than at college, and instanced the training therein at Allan Glen's School as a good example. The boy was better able to gain mechanical skill than the young man, and an indication of his tastes could be ascertained at an early age. He regarded overlapping of subjects taught at the university and the technical college as inevitable. He doubted whether special lecturers for engineering classes in mathematics, physics, and chemistry were desirable, and thought that a suitable choice of examples with a practical application would arouse interest in the subjects. He deprecated the removal of electrical engineering from the University curriculum, for the study of it gave opportunity for very advanced work quite on a par with work in mathematics or physics, and students should not be deprived of the University degree. He instanced the German Technische Hochschulen as being really the technical faculties of the Universities, and granting degrees. In Glasgow the University students could take part of their degree course at the technical college, and there was plenty of room for both institutions. Mr. Henderson.

Mr. J. M. M. MUNRO defined the ideal master and leader of electrical engineering:— Mr. Munro.

We will take it that in bodily and mental strength he is above the average of men, and that he has the moral qualities requisite to sustain a career and secure and deserve respect and confidence.

Mr. Munro. In analysis of fact or problem he is keen and discriminative; in perception he is quick and clear; in conception, imaginative yet cautious. He is ingenious and resourceful of device, broad and sound of judgment, and patient and persevering in the execution of his projects.

He has acquired business habits of order and method, some knowledge of the ways of modern finance, and by intercourse with his fellows he has learned how to lead and influence men.

He has a wide, if general, acquaintance with all the sciences, especially with those which inquire into the nature of the materials and forms of energy most made use of in engineering. He knows all that is known of electrical phenomena. Training in original experiment and research has taught him the methods of scientific thought and practice. He has acquired facility in the application of first principles to the physical effects of the form and relative disposition of materials.

By prolonged personal practice he has become possessed of the instincts and minor knowledge of the artisan as to the behaviour of materials under treatment, the time that work takes to do, and what can be done and how. He is familiar with workshop methods and the use of practical formulæ for obtaining desired results. He is aware of the nature and record of most of the engineering appliances in the market, and of the behaviour and results of all ancient and modern engineering projects at home and abroad.

He has travelled to see and note the devices of many minds and the processes of many industries. He can describe the making of all electrical appliances and the essential properties of the materials used therefor. In all things he knows the limit of his knowledge and where to go to supplement it.

Finally, he has learned to plan his work in terms of commercial conditions.

He described the course through which he had put one boy. At school he took the science side, and spent three months in the last two summers in a carpenter's shop. Six months was then spent in small brass work for switchboards. A first-year session was taken at a technical college, followed by eighteen months with an electric light contractor, while evening classes were attended. A second session at college preceded entrance to a mechanical engineering shop, where eighteen months were spent in fitting and erecting, and one year in the drawing office, while classes in the evening and in the summer were taken in engineering subjects and building construction.

He approved of payment for permission to attend for short periods in a workshop, as giving the lad better opportunities, but considered that full apprenticeship conditions were better for the long workshop course. He strongly recommended a contractor's work for a part of the training, in that it gave experience in a great variety of plant and encouraged self-reliance and resource.

Professor Baily. Professor BAILY (*in reply*) remarked on the difficulty of drawing up a scheme of education for every one on account of wide variation in preliminary training, age, means, and intended future, and said that the

Professor Baily.

scheme given in his paper was restricted to one class of lads—those who had a fair school education up to sixteen years of age and whose fathers desired to give them a good start in life at a reasonable cost. The present arrangements for such lads were much confused, yet they formed the most important source of future leaders of the profession. But the scheme laid down would also fit in with Mr. Pickstone's scheme for educating the workman's son. He thought that Mr. Mavor, in advocating the exhaustive shop training, had in his mind too exclusively the education of a works manager, while the paper dealt with the general training required by all members of the profession, to which special training would be added suited to their future work. The works manager specialised in manufacturing processes and details, and for other men a less elaborate knowledge would suffice.

In his experience the statement that college-trained lads did not take kindly to life in the works was not a fact, but, *per contrâ*, after a long workshop course a lad found a difficulty in picking up college work and was apt to apply his attention to details of practice rather than to general principles, thus missing the scientific and fundamental point of view.

In reply to several speakers he did not intend to imply that evening classes were useless, but he maintained their great inferiority. The teaching was necessarily superficial and partial, partly through lack of time for a sound treatment, but principally on account of lack of knowledge in other subjects, such as heat, chemistry, and applied mathematics. Advanced classes on special technical matters would be very helpful to students who had already taken a full college course and were serving their time in the shops.

The apparent waste of equipment involved in reducing the college work to six or seven months would really be highly beneficial, in that it would permit of extended experimental work in the laboratories by the staff, by research students, and by manufacturers. The test rooms of the latter are rarely equipped for tentative experimental work, and combined work between manufacturers and the college staff would be advantageous to both. But during the stress of the session there was rarely opportunity for continuous research.

He thought that the example of the German Hochschulen proved the exact opposite of Mr. Henderson's views, for while they may be regarded as the technical faculties of the universities, they were completely separate from them in buildings, endowments, staff, and government, and, in fact, corresponded closely to our technical colleges.

In reply to the criticism that the works did not exist for the sake of training apprentices, he would say, in conclusion, that he pleaded only for *some* consideration. The view of immediate profit and loss was shortsighted and would ultimately be to the detriment of the masters, in that they would have an inefficient staff of juniors. He accused them of wasting the educational years of their future assistants in repetition work, instead of encouraging them to make the best possible use of their time in the learning of engineering.

NOTICE.

1. The Institution's Library is open to members of all Scientific Bodies, and (on application to the Secretary) to the Public generally.

2. The Library is open (except from the 14th August to the 16th September) daily between the hours of 10.0 a.m. and 6.30 p.m., except on Saturdays, when it closes at 2.0 p.m.

An Index, compiled by the late Librarian, to the first ten volumes of the Journal (years 1872-81), and an Index, compiled under the direction of the late Secretary, to the second ten volumes (years 1882-91), can be had on application to the Secretary, or to Messrs. E. and F. N. Spon, Ltd., 125, Strand, W.C. Price Two Shillings and Sixpence each.

A further Index, compiled by the Secretary, for the third ten volumes (years 1892–1901) is now ready, price Two Shillings and Sixpence, and may be had either from the Secretary or from Messrs. Spon.

Publishers' Cases for binding Vol. 32 of the Journal can now be had from the Secretary or from Messrs. Spon, price 1s. 6d. each.

JOURNAL

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The Four Hundred and Fifth Ordinary General Meeting of the Institution was held at the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, March 24, 1904—Mr. ROBERT KAYE GRAY, President, in the chair.

The minutes of the Ordinary General Meeting held on March 10, 1904, were, by permission of the meeting, taken as read and signed by the President :—

The names of new candidates for election into the Institution were taken as read, and it was ordered that they should be suspended in the Library.

The following transfers were published as having been approved by the Council :—

From the class of Associate Members to that of Members—

William Brew.	Frank Bartholomew Holt.

Alfred Richmond Sillar.

From the class of Associates to that of Associate Members—

James Bennett Bingham.	Albert Edward Short.
Frederick Walter Purse.	William John Unwin Sowter.

Dr. C. V. Drysdale and Mr. M. Solomon were appointed scrutineers of the ballot for the election of new members.

Donations were announced as having been received since the last meeting to the Library from Messrs. Constable and Co., Mr. J. C. Smail, and G. Semenza; to the *Building Fund* from Mr. P. Hunter Brown and Mr. A. P. Hutchinson; and to the *Benevolent Fund* from the Committee of the Electrical Engineers' Ball, to all of whom the thanks of the meeting were duly accorded.

The following paper was then read:—

DIRECT-READING MEASURING INSTRUMENTS FOR SWITCHBOARD USE.

By KENELM EDGCUMBE, Associate Member, and FRANKLIN PUNGA.

It is nearly eleven years since Mr. James Swinburne read a most instructive paper on "Electrical Measuring Instruments" before the Institution of Civil Engineers. From that day to this it appears that no other paper dealing with the subject in general has been read.*

It is to be feared that this neglect of a question which is admittedly of some importance is traceable to a certain mistrust felt by engineers for the instrument maker and all his works. It is urged against him that he is no engineer, that his instruments, though perhaps very ingenious, are more suited to the laboratory than to the workshop or the station, and, in short, that a lavish use of lacquer and shellac varnish does not in itself constitute a sound engineering job.

That these strictures have been in the past often well merited cannot be denied. For example, in how many instrument firms could it have been said a few years ago that those in responsible positions were, in the true sense of the word, engineers? A great change has, however, lately come about in this direction, and, moreover, the instrument *maker* of yesterday has developed into the instrument *manufacturer* of to-day. If only consulting engineers and users of instruments generally would take a little more interest in them, and would give more thought to the selection of the types best suited to the requirements of the case, there is no doubt that the improvement would be still more marked.

It is in the hope of arousing the interest of electrical engineers in this subject that the present paper has been written. The ground to be covered is so extensive that it has been found impossible to deal with more than a very small portion of it. The authors have, therefore, endeavoured as far as possible to restrict themselves to recent develop-

* An interesting paper on "Measuring Instruments" was read by Dr. Magnus Maclean at the Glasgow Congress in 1901, but it dealt with the manufactures of one firm only.

ments, in direct-reading switchboard instruments and to indicating in what directions modern practice appears to be tending.

GENERAL CONSIDERATIONS.

Accuracy.—As the function of measuring instruments is *to measure*, it follows that accuracy is of paramount importance; in fact, an instrument that is unsatisfactory suffers usually from one of two faults, either it is inaccurate or else it refuses to work altogether. As the most varied ideas of the accuracies to be expected appear to prevail, it may be well to inquire somewhat closely into the matter.

There are two kinds of accuracy which must be carefully distinguished. Firstly, that of the instrument *per se*, and secondly, that found under working conditions of temperature, stray magnetic fields, varying loads and the like. For example, a certain voltmeter may be accurate to one-tenth of one per cent. when tested, and yet read five or ten per cent. wrong when in use on a switchboard. Or again, it is of little avail to know that a particular ammeter can be relied upon to within a quarter of an ampere, if under the conditions of actual working the pointer swings to and fro through an angle equivalent to perhaps ten or twenty amperes.

The great difficulty which is met with in the design of electrical measuring instruments is the smallness of the forces dealt with. It is clear that the greater the force for a given weight, the smaller will be the frictional error; but unfortunately, any attempt to increase the force beyond a certain point is almost invariably accompanied by increased electrical errors, quite apart from the question of excessive power consumption.

A compromise has therefore to be made, in this, as in nearly all engineering matters.

The errors which have chiefly to be guarded against may be roughly divided into :—

1. Mechanical errors in the instrument (*e.g* friction).
2. Electrical errors in the instrument (*e.g.* hysteresis).
3. Mechanical errors of calibration (*e.g.* inaccurate engraving of scale).
4. Errors of reading (*e.g.* parallax).

Amongst mechanical errors, besides friction, must be included set and variation in strength of the springs, want of balance in spring-controlled instruments, and also, of course, any deformations which may have taken place owing, for example, to rough handling.

The electrical errors include those due to hysteresis, eddy currents, frequency, wave form, changes of temperature, weakening of magnets, disturbing magnetic fields and so forth.

Unless great care is taken in marking the scales large calibration errors may creep in, quite apart from the question of the accuracy of the standards used, and in this respect the card or paper scale is as a rule much to be preferred to the engraved or painted dial.

Errors of reading can hardly be looked upon as belonging to the

instrument, as they depend greatly on the skill of the observer; but at the same time, some forms of pointer and scale are much more easy to read than others. This is a matter of considerable importance, which does not always receive the attention it deserves. A pointer which is well adapted for reading at a distance is usually ill-suited to accurate work, and *vice versâ*. Accuracy of reading is obtained in the case of central station instruments by making the scales long and the pointers bold, so that they can be readily seen at a distance; while for testing work a mirror is usually provided under the pointer, which latter should be flattened out so as to present a thin edge to the observer. For this kind of work a scale more than 6 inches in length will be seldom found advantageous, as the increased weight of the moving parts introduces errors which more than counterbalance the increased accuracy of observation.

While the electrical errors, with the exception of those due to external magnetic fields, can be very fairly expressed as a percentage of the reading, the mechanical errors are more accurately given as a constant deflection of the pointer; thus the accuracy of an instrument should strictly be expressed in some such form as $\pm x \% \pm y^\circ$

As a compromise, makers often specify the accuracy as so much per cent. of the maximum reading, as distinguished from a percentage of the actual reading. A better system, and one which is now adopted by at least one firm of consulting engineers in their specifications, is to demand a certain accuracy throughout, expressed as a percentage of the maximum reading, and a greater accuracy from, say, two-thirds of full load upwards.

As regards the actual value of the various errors, it is of course extremely difficult to lay down even approximately what is to be expected. W. Marek (*Elecktrotechnische Zeitschrift*, 1902, p. 447), from a number of very careful experiments, gives the following values for direct-reading laboratory instruments of the very highest class provided with mirrors under the pointer:—

Errors of reading, ± 0·07 mm. (± 0·0028″).
Frictional errors less than 0·1 mm. (0·004″).
Calibration errors, 0·05 to ·1 mm. (0·002″ to 0·004″).
Total mechanical error, say, 0·1 to 0·2 mm. (0·004″ to 0·008″).

The actual length of scale is not stated, but may be assumed to have been about 5 inches. On this assumption the total mechanical error would correspond to an angle of 0·07 to 0·15 degrees. It is probable that for switchboard instruments these figures might be increased five times, and still be well within the mark.

It is even more difficult to assign values to the various electrical errors, but Table I. may serve as a guide. These errors are to a large extent independent of the size of instrument, though as a rule one of medium size, suitable for, say, a 3 in. to 4 in. pointer is more accurate than one having a larger dial.

Power Consumption.—A great deal is often made of the power which is consumed by the various measuring instruments, and although it is of

TABLE I.—ELECTRICAL ERRORS OF VARIOUS TYPES OF INSTRUMENT.

Type.	Hysteresis. — Difference between up & down curves.	Temperature. — Error due to 10° C. change.	Frequency. — Difference of reading from 40 ∿ to 60 ∿	Stray Fields.† — Error due to bar with 1000 amps. at 1 m. from Instrument.
	Per cent. of max. reading.	Per cent. of max. reading.	Per cent. of max. reading.	Per cent. of max. reading.
Direct Current.				
Moving-coil Voltmeter	Nil.	·01	—	·2 } In cast-
„ „ Ammeter	„	·75	—	·2 } iron case.
Moving-iron Voltmeter	1	·5	—	} 1·0 unshielded.
„ „ Ammeter	„	Nil.	—	} ·25 shielded.
Hot-wire Voltmeter ...	Nil.	·75 } For short	—	Nil.
„ Ammeter ...	„	1·5 } periods.	—	„
Alternating Current.				
Moving-iron Voltmeter	—	·5	1·0	} 1·0 unshielded.
„ „ Ammeter	—	Nil.	·5	} ·25 shielded.
Hot-wire Voltmeter ...	—	·75 } For short	Nil.	Nil.
„ Ammeter ...	—	1·5 } periods	„	„
Induction Voltmeter ...	—	·5	4	·5
„ Ammeter ...	—	1·0	15	·5

* In many cases the passage of the current itself will cause a much greater rise of temperature than 10° C., and hence a correspondingly increased temperature error This is particularly the case with moving-iron voltmeters.

† In the case of alternating currents the stray field is assumed to have the same periodicity as the current or voltage which is being measured.

TABLE II.—POWER CONSUMPTION.

Type of Instrument.	Current taken by Voltmeters.	Voltage-drop on Ammeters.	Watts.
Moving-iron Voltmeter, 10 volts ...	·2 ampere	—	2
„ „ 100 „ ...	·06 „	—	6
„ „ 200 „ ...	·05 „	—	10
„ „ 500 „ ...	·04 „	—	20
„ Ammeter, 10 amperes	—	·3 volt	3
„ „ 100 „ ...	—	·03 volt	3
„ „ 500 „ ...	—	·007 to ·01 volt	3·5 to 5
Moving-coil Voltmeter, 0 to 200 volts	·01* ampere	—	2
„ „ 100 to 200 „	·02* „	—	4
„ Ammeter, 500 amperes...	—	·08 * volt	40
Hot-wire Voltmeter, 200 volts ...	·17* ampere	—	34
„ Ammeter, 500 amperes...	—	·2 * volt	100
Induction-type Voltmeter	} Transformers	usually employed {	5 to 8
„ Ammeter			5 to 8
Dynamometer-type—			
Voltmeter, 200 volts ...	·05 ampere	—	10
Ammeter, 100 amperes...	—	·5 volt	50

* The same coil winding is as a rule employed for all ranges, so that these values are independent of the actual range.

the utmost importance in the case of supply meters, on the other hand, for switchboard instruments it is a matter of very small importance. Three ordinary electro-magnetic 200-volt voltmeters, for instance, take less current than a single 8-c.p. lamp, and although the total amount of energy consumed by all the instruments in a station during the year looks very formidable on paper, as a matter of fact the effect on the coal bill (which alone need be considered) is infinitesimal.

Table II. gives approximately the power taken by various types of modern ammeters and voltmeters at the maximum readings.

CHIEF TYPES OF SWITCHBOARD MEASURING INSTRUMENT.

Permanent-Magnet Moving-Coil Ammeters and Voltmeters.

Of the many direct-current instruments in use, the permanent-magnet moving-coil type (variously known as the D'Arsonval, Weston, and Syphon-Recorder), is probably the most extensively employed for central station work. It consists, as usually constructed, of a small coil so pivoted in a strong magnetic field as to be capable of rotation about its axis under the influence of the current flowing through it. The current is led to it by means of springs of non-magnetic material, which also serve to oppose the motion. A cylindrical iron core is fixed inside the coil, and the poles of the magnet are bored out concentrically with it. By this means a uniform field is produced, and as the torque due to the springs is practically proportional to the angle turned through, it follows that this angle is itself proportional to the current. As a result, an evenly divided scale is obtained throughout the whole range.

If the spring is "set up," so that when the pointer is at the beginning of the scale a torque is already exerted by the spring, the pointer will not begin to move until a certain predetermined current is flowing through the coil. An open scale is thus produced at the upper part of the range. The effect is, in fact, the same as though the instrument were provided with a scale, say, two or three times as long as that which it actually has, of which scale, however, only the upper half or third, as the case may be, is visible. This arrangement of course is chiefly of use for voltmeters, and is only applicable to instruments in which the electrical errors are small, as it in reality merely enables more accurate *readings* to be taken, and cannot increase the electrical accuracy of the instrument itself.

The permanent-magnet moving-coil voltmeter is probably as perfect an instrument from an electrical point of view as could well be desired.

In the first place, the magnetic field is strong (the induction in the air-gap is usually about 700 lines per square centimetre), and consequently only a very small number of ampere-turns is required on the moving-coil. This means that the power consumption is small (as is shown by Table II.), and that, further, the moving parts can be made very light. The resistance of the moving-coil is only 10 or 20 ohms, so that the copper can be entirely swamped by a series-resistance having

a negligibly small temperature coefficient. Resistance wire can now be obtained having a resistance 30 to 40 times that of copper, and a temperature coefficient of less than $\frac{1}{100}$ per cent. per degree centigrade. This is important, as the resistance of the copper winding increases about four per cent. of every ten degrees centigrade rise of temperature. The actual temperature coefficient of a 100-volt moving-coil voltmeter is less than one-hundreth per cent. per degree centigrade.

Hysteresis is of course absent, as the magnetic flux is practically constant, although theoretically the ampere-turns of the moving-coil (in practice less than one ampere-turn is required) slightly affect the permanent magnetic field, weakening it over the lower half of the scale and strengthening it throughout the upper.

The chief source of error to be guarded against in a moving-coil voltmeter is the variation with time of the springs and magnet. A great deal of attention has been devoted—chiefly, it must be confessed, on the Continent—to the preparation of non-magnetic springs, with as small a permanent or sub-permanent set as possible, and these can now be obtained, such that, if properly fixed, they introduce practically no error.

The steel used for magnets, as also the methods of hardening and "aging," have been so far perfected that, with proper treatment, little or no trouble is experienced from this cause.

The aging process is looked upon by nearly every maker as his own "trade secret," but as a matter of fact every other maker knows precisely the method he employs, and is at the same time quite confident that his *own* method is the only correct and infallible one. From this fact it may be gathered that the process of "aging" is by no means so complicated a matter as it was at one time believed to be. The methods in use differ but little from one another in principle and consist, as the name implies, in providing artificially those conditions to which the magnet would be later subjected—they are rough usage, demagnetisation, and changes of temperature.

As regards general design, it is important, in order to secure permanence, that the length of the magnet compared with its area be as great as possible, and also that the air-gap be kept as small as possible in length and as large as possible in area.

The dead-beat action in moving-coil instruments is attained, it may be added, by the employment of a copper or aluminum frame, upon which the coil of wire is wound. Motion through the magnetic field generates eddy currents in this frame, and these in their turn damp out the oscillations.

Owing to the fact that only a very small current can be taken through the moving-coil system, it follows that for ammeters intended for currents exceeding, say, half an ampere, shunts must be employed. In order to keep down their dimensions, if for no other reason, it is necessary to proportion these shunts so that the potential difference at their terminals is small (usually less than one-tenth of a volt at full load; see Table II.). Consequently the resistance of the instrument must be low (say from 1 to 5 ohms), and it follows that the proportion borne by the copper winding to the total resistance is always large

(usually from ¼ to ⅕), so that the temperature-coefficient of the whole is by no means negligible, errors of from 0·05 per cent. to 0·2 per cent. per degree centigrade being commonly found. Were the shunts constructed of a metal having the same temperature coefficient as the instrument itself the error would disappear, supposing it possible to ensure that neither the shunt nor the coil were heated by the current flowing through them, or, at any rate, that they both became equally warm. Unfortunately neither of these conditions can be fulfilled in practice, so that all that can be done is to construct the shunt of a material whose resistance is practically unaffected by temperature, and to put as great a length as possible of a wire of a similar material in series with the copper of the moving-coil.

Supposing the magnet employed to be as strong as is consistent with permanence, and the controlling force to have been decided upon from a consideration of the frictional resistance to be overcome, it is clear that a definite number of ampere-turns will be required in the moving-coil. This varies in practice from ¼ to 1 ampere-turn. Such being the case, it can be shown that for any given size of coil the necessary potential difference at its terminals will be inversely proportional to the sectional area of the wire used.

A limit is, however, soon reached, firstly owing to the fact that a decreased resistance means an increased current and with it the chance of contact resistance troubles; and, secondly, owing to the resistance of the leading-in springs or strips. These latter will have a temperature coefficient ranging from 0·1 per cent. to 0·4 per cent. per degree centigrade and a resistance of 0·1 to 0·5 ohm. It can be shown that the best results will be obtained when the resistances of the coil and springs are to one another in the inverse ratio of their temperature coefficients.

Several methods have been suggested for getting over the temperature error. One of the most ingenious is that due to Mr. Albert Campbell and shown diagrammatically in Fig. 1, where *e* represents the moving-coil, while the points *f* and *g* are connected to the shunt. The arms *a* and *d* are composed of copper, *b* and *c* of a material having a negligible temperature coefficient. If the resistance of *a*, *d*, and *e* be 3 ohms each, while *b* and *c* have a resistance of 1 ohm each, practically perfect compensation will be attained. A resistance having as large a negative coefficient as may be required can be constructed as shown in Fig. 2. It consists of a thermometer tube, inside which is stretched a thin platinum wire. Any increase of temperature causes the mercury to expand, and hence to short-circuit more or less of the wire according to the dimensions of the apparatus.

In this connection it may be mentioned that when shunts separate from the instruments themselves are employed great care must be taken either to use the actual connecting wires with which the ammeter has been calibrated, or else others of equal resistance.

Unless carefully shielded, moving-coil instruments are, contrary to the usual assumption, very considerably affected by stray magnetic fields. Campbell* has found that even the earth's field may produce a

* "The Magnetic Fluxes in Meters, etc.," *Phil. Mag*, S 5, vol. xlvii., p. 1 (1899).

change of flux of as much as 0·1 per cent. in an unshielded permanent magnet with a moderate air-gap. It must be borne in mind that although the permanent magnetic field is in itself fairly strong, the presence of the iron very materially concentrates any disturbing field, so that its effect is greatly increased. The ordinary cast-iron case appears to be quite an efficient shield for switchboard instruments. When using portable moving-coil instruments (which are usually fitted in wooden cases) great care should be taken to keep them well away from dynamos and motors, and, which is equally important, from one another also. Two such instruments standing side by side may frequently read 5 or 10 per cent. wrong from this cause. The effect of stray fields can be allowed for in the case of portable instruments by taking a second reading after

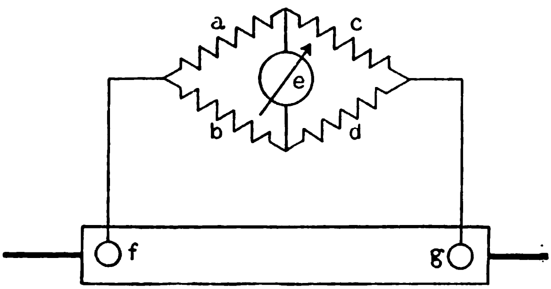

FIG. 1.

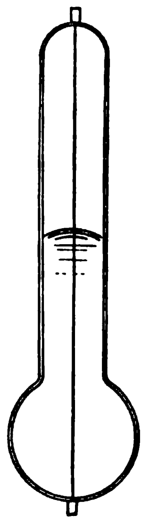

FIG. 2.

having turned the instrument round through 180 degrees. The mean of the two readings will give the correct result. Another source of error in the case of moving-coil ammeters is thermo-currents due to unequal heating of the two terminals of the shunt. The thermo-E.M.F. between copper and several of the alloys used for the construction of shunts is quite appreciable; for example, copper and constantan (which is used very extensively on the Continent) have a thermo-E.M.F. of 37 micro-volts per degree centigrade. It frequently happens that one terminal of a shunt is connected to a large mass of metal, which serves to conduct away the heat more rapidly than is the case with the other terminal, and unless attention is paid to this point, errors of as much as 2 per cent. of the full scale reading may often be traced to this cause.

MOVING-IRON INSTRUMENTS.

The instruments which are variously known as "soft-iron," "electro-

magnetic," "gravity controlled," and other equally inappropriate names, may, in the authors' opinion, be better described as "moving-iron" instruments, as they one and all depend on the movement of a piece of soft iron from one part of the field to another. They may be roughly divided into three classes according as the fixed coil acts on:

1. A single moving iron mass.
2. A fixed mass of iron attracting or repelling a moving mass.
3. A combination of attracting and repelling irons.

Of these the second class is by far the most used.

Almost all the errors to which moving-iron instruments are liable, apart from those of a purely mechanical origin which they have in common with all other instruments, and which have been already alluded to, are traceable to hysteresis in the iron. This has firstly the effect of causing the readings taken with a rising current to be lower than those obtained with a falling current, and further, owing to hysteresis, an instrument calibrated with direct current will read low on an alternating circuit. In order to reduce hysteresis to a minimum, it is essential that the magnetic lines should lie in the iron for only a small portion of their total length, and further, that the iron should be as short as possible, so that the demagnetising effect of the ends may be a maximum effect. It is clear that if the iron is saturated, the effect of hysteresis will be small; and on the other hand, if the flux density is kept very low, the same end will be attained. In order to obtain the minimum hysteresis error then, the mass of iron should either be very small or very large. The former alternative means reduced power, and the latter increased weight.

There is a further disadvantage in the high density arrangement when the instruments are to be used for alternating currents, in that, if the iron is saturated, the force at each instant will be approximately proportional to the instantaneous value of the current, so that the instrument will indicate the *average* value instead of the R.M.S. (effective) value. Now, the ratio of the average to the effective value depends very much on the wave-form, so that such an instrument if calibrated with a sine-wave current, for example, will give altogether incorrect readings with a peaky or flat-topped wave.

In those instruments, on the other hand, which employ a low induction, the force is roughly proportional to the square of the current, and therefore the instrument shows very approximately the effective value irrespective of wave-form.

It is often assumed that an instrument whose indications are practically independent of frequency will also be independent of wave-form, and *vice versa*. While this is true for all errors which depend purely on self-induction, it is far from being true when the error arises from the iron itself. Every instrument whose indications are not dependent on the square of the current must of necessity give inaccurate readings with any other wave-form than that with which they are calibrated, although with a given wave-form its indications may be entirely independent of frequency.

This difference is strikingly shown in Fig. 3, which is taken from results obtained by Benischke (*Electrotechnische Zeitschrift*, 1901, p. 301) with an instrument consisting of a long solenoid into which is

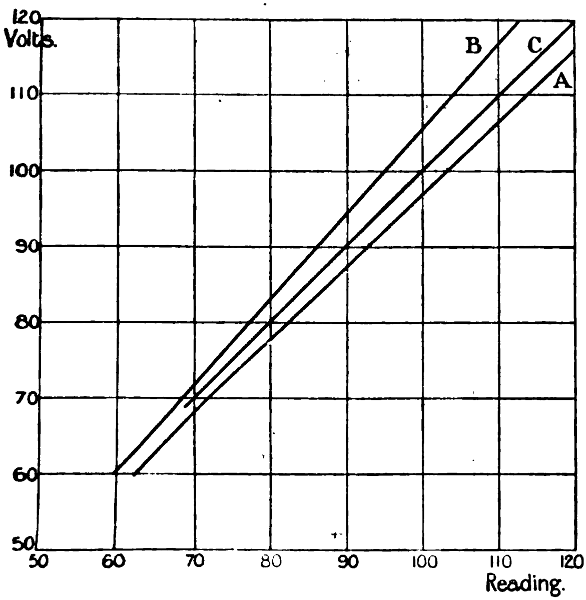

FIG. 3.

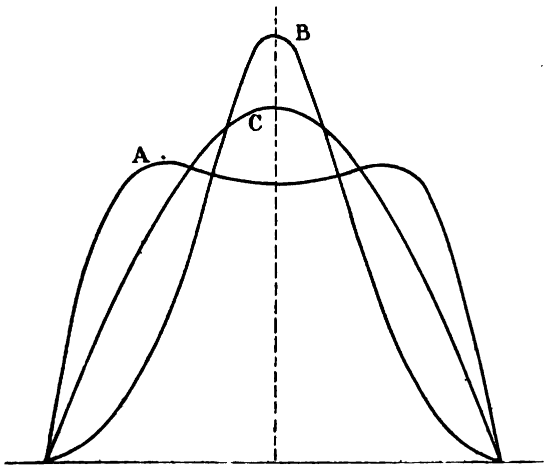

FIG. 4.

sucked a thin iron wire highly saturated. The effect of frequency was found to be quite negligible, whereas the wave-forms A and B (Fig. 4) gave a difference of reading of over 12 per cent. The values of

the constant $\frac{\text{maximum value}}{\text{effective value}}$ were Curve A, 1·2, and Curve B, 1·76. These wave-forms probably differ from a sine wave (ratio 1·41) by about as much as any which would be met with in practice.

This must be regarded as an exceptional case, as in a well-designed instrument the error from this cause should not amount to more than, say, 1 per cent., and in an instrument working at a low density to considerably less. Figs. 5 and 6 show the effect of frequency on two distinct types of ammeter. Readings were in each case taken with direct

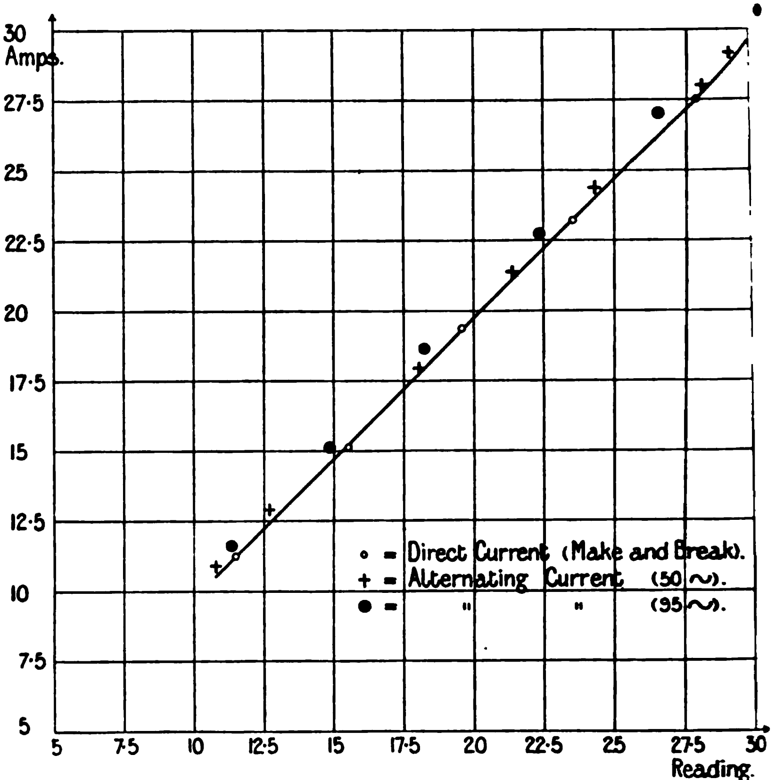

FIG. 5.

current, and with alternating current at 50 ∿ and at 95 ∿. Fig. 5 refers to a 30-ampere ammeter of a well-known make having fixed and moving irons. Fig. 6 gives the results obtained with a 50-ampere Everett-Edgcumbe "Universal" ammeter. This latter instrument is based upon a principle due originally to Uppenborn, and was first put upon the market by Messrs. Siemens & Halske, of Berlin. It is practically a modification of the well-known Miller type; the shape of the iron used, however, is different. It consists of a number (usually three) of soft iron discs of a special shape, which are mounted eccentrically on the spindle of the instrument, and are drawn by the current into the flat

coil. The section of the iron and the ampere-turns of the winding are so chosen that only a very low flux density is employed, with the result that the hysteresis error is reduced to a minimum, as are also the errors due to wave-form.

A further advantage of this construction in the case of voltmeters is that the cross sectional area of the coil is so small that the self-induction is quite negligible for all ranges over, say, 80 volts. This is well seen in Fig. 7, which shows the difference of reading between direct

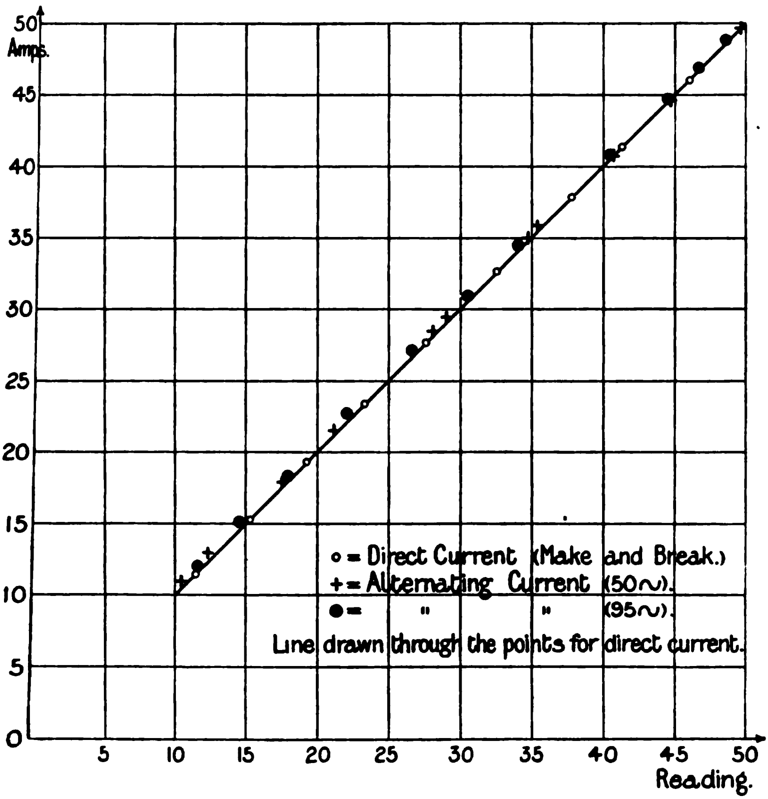

FIG. 6.

current and alternating current at 50 ∿ and alternating current at 90 ∿ in the case of a 120-volt voltmeter. Fig. 8, on the other hand, shows the corresponding results obtained with a 130-volt voltmeter of another very well-known make. It need hardly be said that the instrument whose readings are recorded in Fig. 7 is practically unaffected by changes of wave-form, while that in Fig. 8 is considerably affected by both wave-form and frequency.

A great drawback to the use of moving-iron instruments for many purposes is that the lower portion of the scale is always very cramped.

This is due to the fact that the scale in reality roughly follows a square law, and is only artificially made approximately even. The scales of moving-iron ammeters are seldom marked below one-tenth of full load, and the scale is only approximately even from one-fifth of full load upwards. This fact is, as a rule, not sufficiently born in mind when selecting an ammeter for a particular purpose; and when two instruments of different ranges are sold at the same price, the customer is, in our experience, apt to choose the higher, apparently under the impression that he is getting more for his money by so doing.

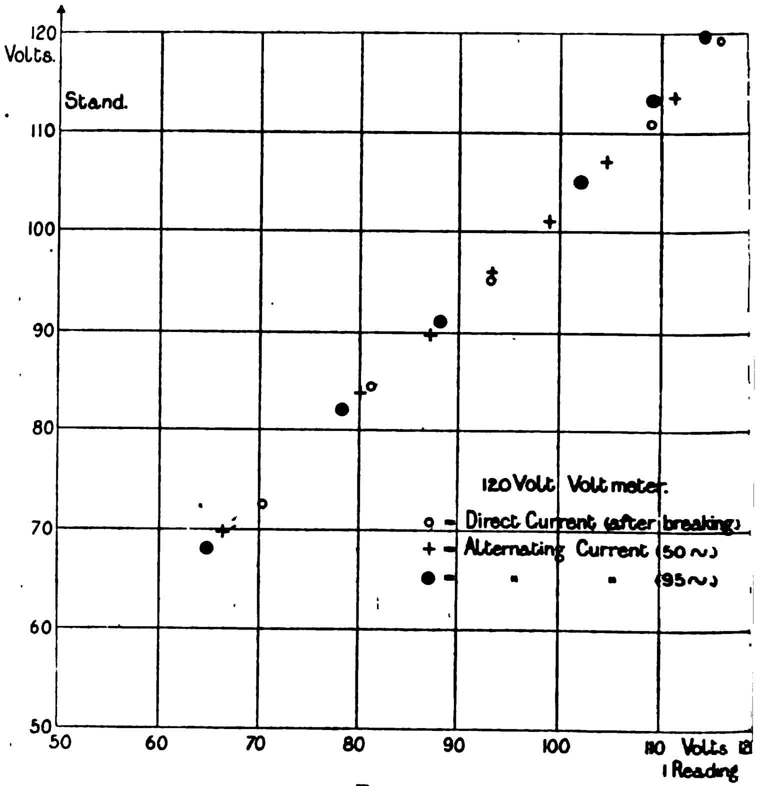

FIG. 7.

In the case of voltmeters, a decided advantage can be secured in that the scale may be enormously opened out at the upper or working portion of the range, while at the same time the zero is still visible, which is often useful.

Magnetic Shielding.—For switchboard work the question of how far the instruments employed are likely to be affected by stray magnetic fields becomes a most important one, particularly where moving-iron instruments are employed. The effect is somewhat difficult to predetermine owing to the complicated nature of the resulting fields; but

other things being equal, an instrument which in itself utilises the strongest field will be the least affected.

In Fig. 9 curves are given showing approximately the effect, on three types of moving-iron instrument, of a bus-bar carrying 1,000 amperes and placed at a distance of one metre from the instrument coil, and in such a position that its effect on the reading is a maximum. The numbers along the bottom (abscissæ) show the reading as a percentage of the full load (assumed to be 100 in each case), while the

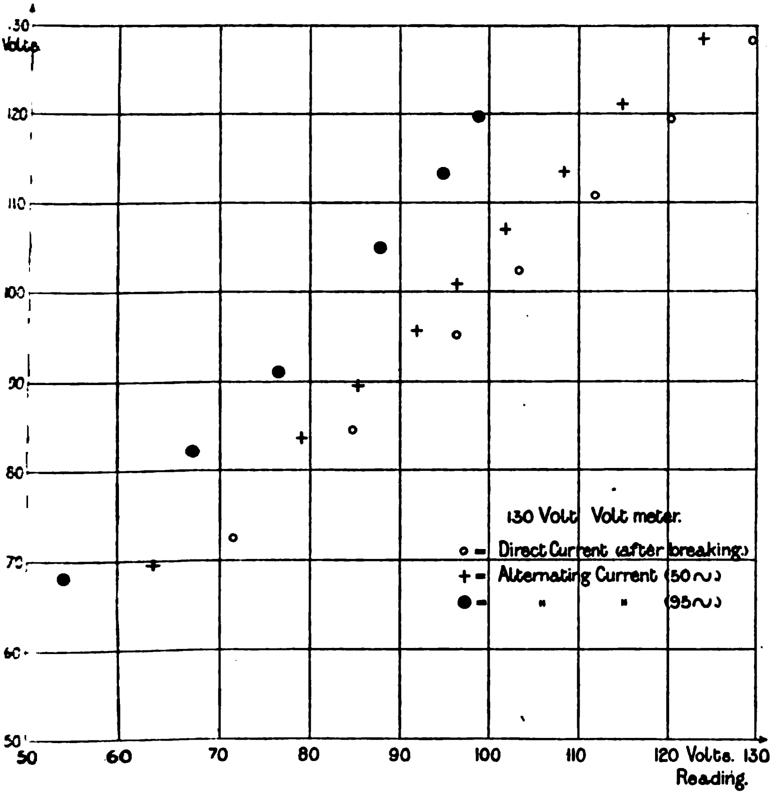

FIG. 8.

ordinates represent the error, as a percentage of the full-load reading of the instrument.

Curve A shows the effect on a 30-ampere moving-iron ammeter of a well-known make in a brass case (ampere-turns 450). The movement consists of a fixed mass of iron repelling a moving mass. It will be noticed that the percentage error is practically constant; the effect, in fact, at zero was as great as at the end of the scale.

Curve B was taken with an Everett-Edgcumbe 10-ampere "Universal" ammeter with cast-iron case removed (ampere-turns 400). It will be seen that the error falls off very rapidly as the load increases.

Curve C refers to the same instrument after replacing it in its cast-iron cover, while curve D shows the effect of the addition of an iron back to the instrument case. That is to say the instrument was of the standard "Universal" type.*

Curve E shows the error produced in a Siemens and Halske 130-volt voltmeter of a type which has already been described, and which is constructed on much the same principle as the instrument just mentioned. It is fitted in a brass case, and is shielded by the coil being placed on a sheet of soft iron and enclosed on the three remaining outer edges by a strip of soft iron bent round it so as to form, as it were, an open-ended case. Although as shown in Fig. 15 in the case of Curves B, C, D and E the percentage error increases as the load is decreased, it was found to be quite negligible at zero.

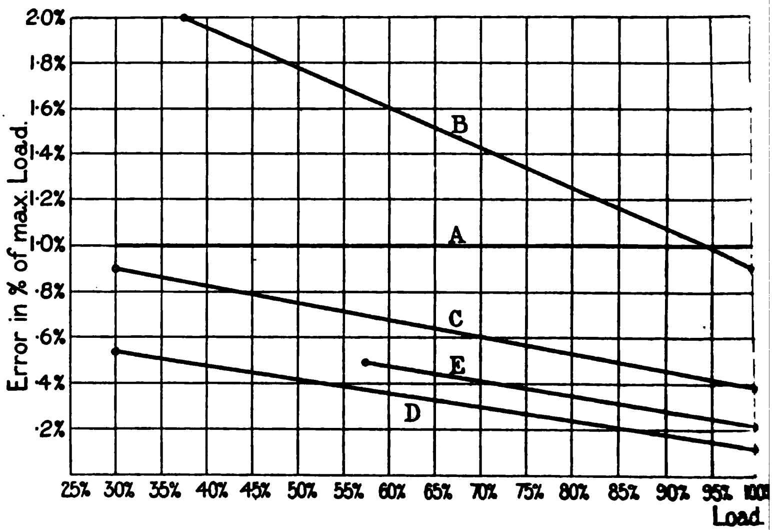

FIG. 9.

In this connection a word or two may not be out of place as to the effect of shields on the accuracy of the instruments to which they are applied. Attempts were at one time made to fit the ordinary moving-iron instruments into cast-iron cases, with the result that, as was to be expected, the hysteresis error was very much increased. It is clear that if the ordinary bobbin be placed in a cast-iron case practically the entire path of the lines of force, after leaving the coil, will lie in cast-iron, with the result just mentioned. In an instrument, however, of the Siemens and Halske or the Everett-Edgcumbe type, a cast-iron case can be employed with impunity, owing to the fact that only a

* In the case of Curve C the working parts of the ammeter were all mounted on a base of insulating material, while in the case of Curve D a cast-iron back was used such as is employed in the more modern instruments of this type.

very small part of the return path of the lines lies on the iron of the case.

The curves in Fig. 9 were actually taken with a coil of large diameter, through which currents of various strengths could be passed. Its dimensions were so calculated as to be equivalent to a 'bus-bar of infinite length placed at a given distance from the instrument, and the value of the constant was afterwards checked and found to agree with the calculated value, within the limits of accuracy attainable in the readings.

In practice, the fact that the 'bus-bars are not of infinite length causes the errors to be slightly less than those given, but the difference is extremely small, and is on the right side. If the actual length of a 'bus-bar is four times its distance from the instrument, the disturbing effect will be 3 per cent. less than if infinitely long.

The curves were taken, as has been already stated, with the coil in its most effective position. The effect in any other position was found to be, as would be expected, proportional to the cosine of the angle between the two positions. The effect is further directly proportional to the current flowing, and inversely proportional to the distance between the instrument and the 'bus-bar. The values have been reduced to 1,000 amperes at a distance of one metre.

In the case of instruments in which the axis of the coil is horizontal, and perpendicular to the 'bus-bar, the worst possible position for the 'bus-bar is above or below the coil, while when the axis of the coil is vertical the worst position is directly behind the instrument.* In order to reduce the effect of stray fields to a minimum, the + and — 'bus-bars should be kept as near together as possible, and the conductors carrying current to the instrument should, particularly in the case of heavy currents, be brought near together.

Damping.—Before leaving the question of moving-iron instruments mention must be made of the very important question of "dead-beatness." Simple as it may seem in view of what can be done in this direction in the case of the moving-coil instruments, it is an extremely difficult matter to devise an efficient damping arrangement for a moving-iron instrument, owing chiefly to the relatively large mass of the moving parts. The importance of the subject is enormous; in fact, an ammeter which is not damped is for many purposes practically useless. It is hardly then to be wondered at that numerous attempts have been made to overcome the difficulties encountered.

The three methods of damping most used depend on :—

1. Viscosity of liquids;
2. Electrical eddy-currents;
3. Air friction.

Of these devices such as depend on the viscosity of liquids are the easiest to apply, and have therefore been most largely employed in the past. It is essential that the surface exposed to the liquid (usually oil)

* In the latest form of "Universal" instruments it may be mentioned that the axis of the coil is parallel to a horizontal 'bus-bar, so that the disturbing effect is nil.

should remain continually immersed, otherwise a certain quantity will adhere to that part which is drawn out of the liquid, and "creeping" in the reading will inevitably result.

Probably the oldest and most successful application of oil damping is that which Lord Kelvin uses in his multicellular electrostatic voltmeters. The axis of rotation being vertical, the entire surface remains continually immersed, and if the wire attaching the damping disc to the instrument is in line with the axis of rotation, creeping is practically avoided. Moreover, the other great objection to the system, namely, the inconvenience of having oil in an open vessel, is less felt in this case, owing to the fact that the instrument itself requires very delicate handling.

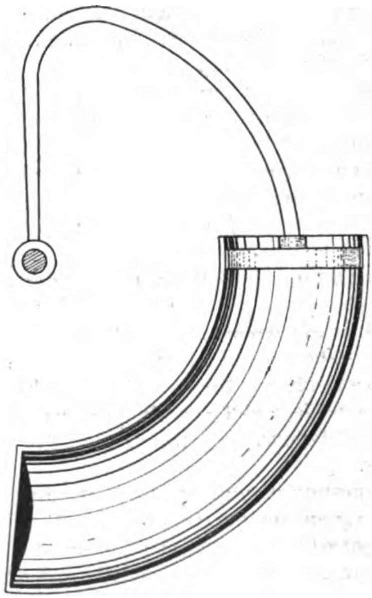

FIG. 10.

An ingenious attempt to overcome the objection to the open oil vessel was made in 1890 by Mr. Frank Holden, of the Thomson-Houston Co., who placed a small quantity of glycerine in an hermetically closed drum carried by the spindle of the instrument. Owing to the fact, however, that as the drum revolved an entirely new surface was being continually presented to the oil, considerable creeping resulted, and the device has, we believe, been now practically abandoned.

At first sight, method two, viz., that depending on eddy-currents, would appear to be the most promising, but, as a matter of fact, several difficulties present themselves. The presence of a permanent magnet close to the coil of a moving-iron instrument intended for direct current has a considerable effect on the readings, and although the instrument is of course graduated with the magnet in position, at the same time the small magnets with comparatively large air-gaps which have to be employed have a great tendency to lose their strength, so that the effect on the readings is a variable one. With alternating currents also the field due to the instrument coil tends to demagnetise the permanent magnet, unless the latter is shielded. The method is also clearly inapplicable to moving-iron instruments which are intended to be used for both direct and alternating current. For hot wire and electrostatic instruments the device has, however, been employed with success.

Air damping, although doubtless used before any other system for galvanometer and other laboratory instruments, has only within the last few years been employed for commercial ammeters and voltmeters.

Messrs. Evershed and Vignoles were probably the first to apply it to such a purpose. Their arrangement consists of a sector-shaped box fitted above the coil of the instrument, and in which moves a light vane attached to the spindle. The clearance is reduced to a minimum, and hence considerable damping is obtained. This device has since been adopted in a more or less modified form by several Continental manufacturers.

Fig. 10 shows a form of damping arrangement introduced by Messrs. Siemens and Halske some three years ago. It consists, as will be seen, of a curved cylinder in which works an aluminium piston, without, however, touching the walls of the cylinder. This device has recently been adopted by Messrs. Everett, Edgcumbe & Co. for use in their commercial ammeters and voltmeters. When it is said that the clearance all round does not exceed 0·015 inch, it will be seen that the mechanical difficulties of manufacture are great; but as regards durability and reliability, it is found from experience as a matter of fact that blows severe enough to bend the pointer have no effect whatever on the damping arrangement. The cylinder, in fact, by checking the motion of the piston performs much the same function as does the pointer catch, which is often fitted to portable instruments. The piston, moreover, in travelling to and fro, keeps the cylinder clear of dust, while the reverse is the case with magnetic damping, as small particles of iron have a great tendency to accumulate in the air-gap.

It will be noticed that this method, as also the magnetic, is equally applicable to portable instruments as it works equally in any position.

Summing up, it may be said that devices depending on fluid or mechanical friction are unsatisfactory, and that a successful damping arrangement must be free from all links or cords and must not require levelling.

Hot-Wire Ammeters and Voltmeters.

The oldest instrument of this type, namely the voltmeter due to Major Cardew, is too well known to need description. At a later date Messrs. Hartmann and Braun introduced hot-wire instruments in which, by an ingenious double sag arrangement, great magnification was obtained. Recently attempts have been made by various Continental firms to obtain the enormous magnification which is necessary, by various combinations of levers and so forth, but as a rule with rather doubtful success. The chief difficulty in the design of a hot-wire instrument is that the expansions dealt with are so minute that when the necessary magnification has been taken into account the available power is very small. In the case of ammeters, also, it is necessary to reduce the size of the wire employed to a minimum in order to avoid excessive sluggishness. It is, of course, possible to place several wires in parallel or to connect up a single wire in several parallels, but in any case, for currents above, say, 10 amperes, a shunt becomes necessary with all its attendant drawbacks of large power-consumption, high temperature errors, contact troubles, and so forth.

Amongst the disadvantages possessed by hot-wire instruments as a class must be mentioned the following, though it must not be thought that all types suffer equally—errors 2 and 3, for example, have been rendered almost negligible in some makes of voltmeter at any rate:—

1. Large power consumption. The drop in ammeters ranges from 0·1 to 0·5 volts, and the current taken by voltmeters from one-third to one-eighth of an ampere.

2. Uncertainty of zero.

3. Gradual increase or decrease of reading when left in circuit. In order to render the reading of the pointer independent of external temperature, the supports of the hot wire are usually mounted on a base having a coefficient of expansion equal to that of the wire itself, but as the latter takes up its temperature much more rapidly than the former a gradually decreasing deflection is obtained when the instrument is left in circuit.

4. The scales are usually excessively open at the end owing to the fact that the extension is roughly proportional to the square of the current or voltage as the case may be. While in the case of ammeters this is a distinct disadvantage, in the case of voltmeters, which are as a rule only used at the upper part of their ranges, it gives a very useful scale.

5. The wires are usually worked as hot as possible so as to get the maximum possible extension, hence a comparatively small overload may destroy the wire. A fuse or cut-out in the circuit will not, as a rule, save the instrument, as the mass of the hot wire is so small that it takes up its temperature more rapidly than the fuse. The employment has been suggested of a small cut-out inside the instrument worked by the expansion of the wire itself.

After what has been said it may well be wondered that these instruments have been used so largely in the past, particularly on the Continent, but it must be remembered that they were introduced at a time when there was no dead-beat instrument to be had, at any rate for alternating currents. Moreover, the advantage of being able to employ a shunt for various ranges, and of being able to calibrate with direct current and then to use the instrument with a fair degree of certainty for alternating current of any frequency, proved of great importance, particularly for laboratory use. It should be remembered also that hot-iron instruments are unaffected by stray magnetic fields.

With the exception of the Cardew voltmeters, hot-wire instruments have never found great favour in this country, and it seems probable that for central station use they will gradually give place to instruments of the various other types.

Electrostatic Voltmeters.

As standards for laboratory use the multi-cellular electrostatic voltmeters of Lord Kelvin leave little to be desired for the measurement of fairly low voltages, as, of all instruments, those based on the electrostatic principle are the least liable to change with time and, moreover, in many cases the fact that no current is taken is of importance. Like

hot-wire instruments, also, they can be calibrated with direct current and used with confidence for the measurement of alternating voltages at any frequency. For switchboard use the advantages are, however, less obvious, and for direct-current work they are not to be compared with the moving-coil type.

The case of high-tension circuits is, however, different, and where voltmeters are to be connected direct to a high-tension circuit the electrostatic type is practically the only one available. Now, however, that it is becoming customary to work high-tension voltmeters off the low-tension side of step-down transformers, it is probably merely a question of price which type of instrument is employed.

The chief advantages which can be claimed for electrostatic voltmeters are that they consume no power, and that they are unaffected by stray magnetic fields. Electrostatic fields, however (set up, for example, by such a simple process as rubbing the glass to clean it), may cause considerable errors. Professor Ayrton and Mr. Mather suggested the use of a transparent conducting varnish to get over the trouble,* while Messrs. Hartmann and Braun cover the glass with meshes of a conducting metallic paint.

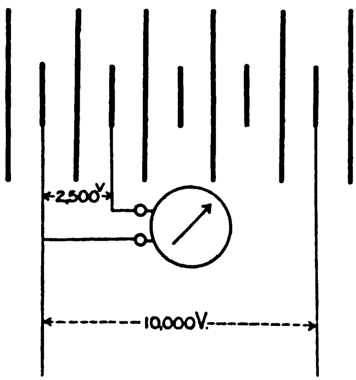

FIG. 11.

The great difficulty met with in the design of electrostatic instruments is that the forces dealt with are so small that frictional errors are difficult to avoid. In order to increase the power, the distance between the fixed and moving parts has to be reduced to a minimum, with the result that considerable trouble is often experienced with the ordinary electrostatic voltmeter, owing to sparking across, should there be any abnormal rise of voltage such as may be caused, for example, by switching a dead-main into circuit. In order to prevent this, the segments should be lined with mica, and a high resistance should always be provided in series with the instrument. This is a much better safeguard than a spark-gap, which is at best a weak point in what is probably otherwise a most carefully insulated system. A liquid resistance sealed into a glass tube is very handy for this purpose.

Messrs. Ferranti have recently installed some high-tension electrostatic voltmeters, connected through liquid resistances so arranged that should a short-circuit occur, the water with which they are filled is boiled away by the heat generated and thus the circuit broken. The arrangement is said to work extremely well in practice, and is certainly made up in a particularly handy and workmanlike form.

In order to increase the range of electrostatic voltmeters and at the

* A coating of gelatine and sulphuric acid protected by ordinary varnish is said to be perfectly satisfactory.

same time to avoid sparking access, Dr. Benischke * employs a system of condensers which may be compared to a volt box. Fig. 11 shows the arrangement diagrammatically—an electrostatic voltmeter reading up to, say, one-fourth of the full voltage, is connected across one of the condensers, while three others are connected in series with it. The five condensers are connected across the main voltage to be measured, and the voltage at the terminals of the voltmeter is inversely proportional to the capacities. Voltmeters on this principle can be constructed up to 40,000 volts.

Dynamometer Type Ammeters and Voltmeters.

During the last few years several firms have introduced direct-reading dynamometers, both as ammeters and voltmeters. The object in view has usually been to produce an instrument which could be used with both direct and alternating current, and whose indications were independent of frequency. These advantages are possessed by the well-known Siemens dynamometer ammeter, whose chief drawback is that

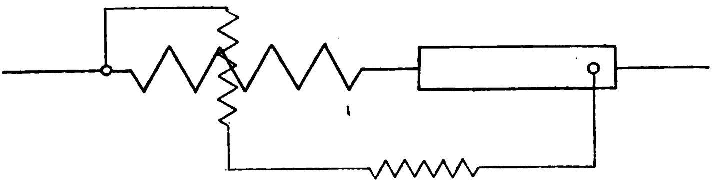

Fig. 12.

its field is so weak that the readings are seriously affected by stray magnetic fields. The earth's field alone may cause an error of as much as two per cent., when using the lower half of the scale. The usual mercury cups are also a source of trouble, and have in the more recent modifications been dispensed with. As the result of this, however, not more than, say, one ampere can pass through the moving-coil, so that a shunt becomes necessary in the case of ammeters. It is, moreover, imperative that the ratio of the self-induction to the ohmic resistance be the same both in the moving-coil and in the shunt, or the readings will clearly be different with direct and alternating current, and will also depend considerably on the frequency and wave-form of the latter.

Owing to the weak field employed (usually not more than one-tenth of that of a permanent-magnet moving-coil instrument), the ampere-turns of the moving-coil must be considerable, so that a much greater fall of potential is required over the shunt. Moreover, the power necessary to overcome friction is usually greater than that required by a moving-coil instrument owing to the greater weight of the moving parts. As a rule, twenty or thirty ampere-turns are employed in the

* Since writing the above, a paper has been read by Professor Marchant and Mr. Worrall before the British Association (1903), drawing attention to the possibilities of this method, which was originally due to W. Peukert (*Elektrotechnische Zeitschrift*, vol. xix., p. 50).

moving-coil, and in order to keep down the temperature coefficient of the moving system, a drop of nearly half a volt is required.

Messrs. Siemens and Halske obtain good results by a sort of compromise. This consists in including the fixed coil of the instrument as part of the shunt to the moving-coil (as shown in Fig. 12). By this means the shunt not only possesses a certain amount of self-induction but its temperature coefficient is also appreciable; and both coefficients can be made about equal to those of the moving-coil.

As was pointed out, however, when speaking of permanent-magnet moving-coil instruments, it is impossible, owing to the unequal heating of shunt and moving-coil, to eliminate entirely temperature errors by this means; although as the temperature coefficient of the moving system is in itself not more than, say, one-tenth per cent. per degree centigrade, the error is very small.

Another method of increasing the range of such an instrument is to employ a series transformer. This, however, as a rule, introduces

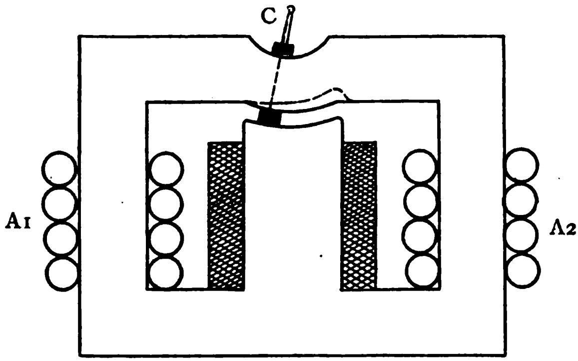

FIG. 13.

errors with changes of frequency, and is therefore chiefly of use for switchboard instruments. This matter will be dealt with further when treating of current transformers.

In the case of voltmeters the fixed and moving coils are connected in series, which means that the self-induction and also the temperature coefficient are by no means negligible for low-range instruments. In the case of a 100-volt instrument, however, the temperature coefficient need not exceed one-tenth per cent. per degree centigrade, while the difference of reading between direct current and alternating current of 100 ∿ due to self-induction, would amount to perhaps one-tenth per cent.

The Allgemeine Elektricitäts Gesellschaft construct such an instrument, but they surround the fixed coils with a laminated iron shell, so that the return path of the magnetic lines lies wholly in iron. This has the effect of increasing the power and reducing the disturbing influence of stray magnetic fields.

It is worth noting that the errors likely to be introduced by eddy currents in the various parts, are extremely small, owing to the fact that

the eddy currents lag practically 90 degrees behind the currents producing them, and since the currents in the fixed and moving-coils are in phase with one another, the eddy currents are out of phase with both. Further reference will be made to eddy currents when dealing with Wattmeters.

Induction Type Ammeters and Voltmeters for Alternating Currents.

These instruments, which are variously spoken of as being of the "Induction," "Ferraris," and "Rotary Field" type, were due to Ferraris, who devoted a great deal of attention to the application of Rotary Fields to Measuring Instruments. In fact, owing, curiously enough, to the low efficiency which he regarded as inseparable from induction motors, he believed that the latter could never become a commercial success. In spite of his work, however, it was not until several years later that the subject of induction instruments received much attention.

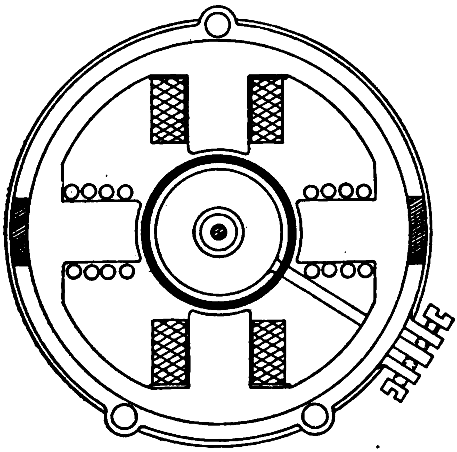

Fig. 14.

Undoubtedly the first ammeters and voltmeters constructed on this principle were due to Mr. James Swinburne. The principle of action is shown in Fig. 13. The actual winding shown in the figure is that of a wattmeter. Supposing the instrument to be constructed as a voltmeter, the coils A1 and A2 are highly inductive, so that the flux in the limbs on which they are wound lags nearly 90 degrees behind the voltage producing it. An E.M.F. is thus produced in the small coil, which being pivoted at C is free to swing in the air-gap. The third fixed coil (which is also connected across the mains whose voltage it is required to measure) has a considerable non-inductive resistance in series with it, so that its current is practically in phase with the voltage; and therefore also with the current in the moving coil. A torque is thus produced which is practically proportional to the square of the voltage. If an even scale is required, the air-gap can be so shaped as to gradually lengthen out towards the upper end of the scale (as shown by the dotted line), so that the flux gradually falls off as the deflection increases. Ammeters and wattmeters can be constructed upon the same principle.

Following the lead of Ferraris, most of the ammeters and voltmeters consist of a disc or drum of copper or aluminium which is caused to rotate

owing to currents induced in it by means of a rotary magnetic field. The motion is usually opposed by a spring.

In the case of voltmeters the necessary splitting of phase is, as a rule, produced, as in the Swinburne instruments, by connecting one coil in series with a non-inductive resistance and the other with a choking coil. In ammeters the current is split in like manner into two parts, one circuit being as inductive and the other as non-inductive as possible.

A disadvantage common to all rotary field instruments consists in the fact that the torque is dependent on the frequency. In the case of the ammeters where the total current is, of course, fixed, any increase of frequency means a corresponding increase of torque; so that the deflection produced is almost proportional to the frequency. With

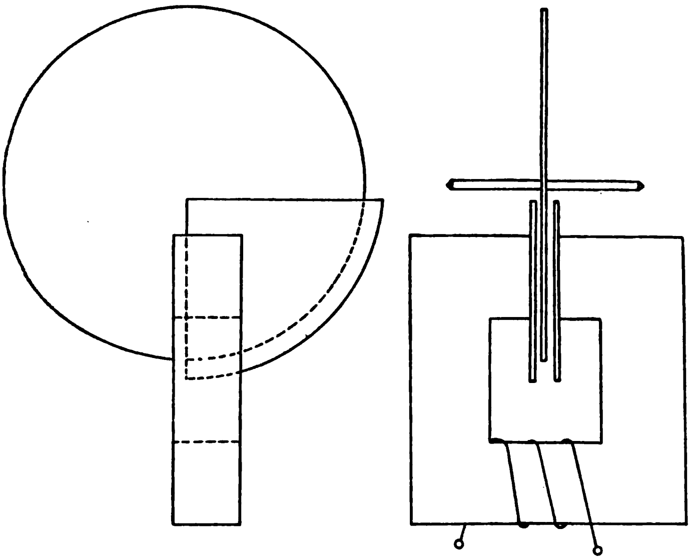

FIG. 15.

voltmeters, on the other hand, any rise of frequency means also a decreased current through the choking coil; the two effects oppose each other, so that the resulting deflection is less affected.

Fig. 14 shows an instrument of this type as constructed by Messrs. Siemens and Halske. Four coils are used on a frame resembling a four-pole dynamo. The opposite coils are connected in series, one pair being inductive and the other non-inductive.

In another type of induction instrument the rotary field is produced by means of a short-circuited winding, often consisting (as in the case of the instruments of the Allgemeine Elektricitäts Gesellschaft) merely of a sheet of copper or soft iron. Fig. 15 shows this instrument diagrammatically. In this case only one coil is required, whilst of the lines of force some go directly through the movable copper disc,

whereas the remainder have to pass through a thick sheet of metal. Eddy currents are induced which re-act on the field, causing it to lag, so that a rotary field is produced.

Benischke finds that an increase of frequency from 40 to 60 ∿ per second produces an error of from 3 to 4 per cent. in the case of voltmeters, but of as much as 20 to 25 per cent. in the case of ammeters.

As regards wave-form, on the other hand, unless the iron cores are saturated, variations cause but small errors in the readings, for the reasons which have been already stated.

Since the magnetic fields employed in induction type instruments are strong, the effect of stray fields is extremely small, and moreover, it is easy to so arrange the various coils that any external fields which may exist have the effect of strengthening one set while weakening the other, so that the total effect is nil. Changes of temperature also have a very small influence on the readings.

For laboratory use these instruments are of very small value, owing to the fact that they are so much affected by changes of frequency; for station use, however, where the frequency is practically constant, they possess many advantages.

Wattmeters.

Probably no modern instrument has come in for so much adverse criticism as the alternating current wattmeter. This is doubtless in part due to the fact that in the past many instruments which were anything in the world except wattmeters have been put upon the market under that name; and, secondly, to the extreme difficulty which there is, in determining the accuracy or otherwise of a wattmeter at low power-factors.

At the present time there is no reason whatever for this scepticism. The principles upon which they work are perfectly well understood, and it is merely a question of experience in the design, and construction of the parts so as to reduce the various errors to a minimum, that makes the difference between a good and a bad instrument.

Direct-reading wattmeters may be divided into three classes:—

1. Dynamometer type.
2. Rotary-field type.
3. Hot-wire type.

Of these, the dynamometer type has been by far the most employed, and for accurate work is undoubtedly to be preferred. Rotary-field wattmeters, however, possess many advantages for switchboard work, while hot-wire wattmeters have been suggested, notably by Mr. Michael B. Field, and are chiefly of interest owing to the fact that the range of the instrument can be easily varied by means of a shunt.

Dynamometer-type Wattmeters.—The chief errors to be guarded against in these instruments are:—

1. Self-induction and capacity of the moving-coil and its series-resistance.
2. Eddy currents.
3. Effects of external magnetic fields.

It was at one time thought that practically the only error of any importance was that due to the self-induction of the moving-coil. It is now recognised, however, that not only can this be rendered quite negligible, but that care has even to be taken that the series-resistance introduces no capacity. Thus the ordinary non-inductive method of winding, in which two wires are laid on a bobbin or frame in parallel, possesses not only the disadvantage that neighbouring wires have often a large difference of potential between them, but also that it has a very considerable electrostatic capacity. The series-resistance of wattmeters, and in fact of all alternating-current instruments, should always for this reason be wound in sections. The capacity is then inversely proportional to the square of the number of such sections into which the resistance is divided. The self-induction of the moving-coil circuit of a well-designed wattmeter should not exceed 10 milli-henries. The current taken at full load would be about one-thirtieth of an ampere, and in that case the error in a 100-volt instrument would be less than one-half per cent. with a power-factor of 0·2, and becomes quite negligible for all power-factors greater than, say, 0·6.

The errors due to eddy-currents, which have often been neglected, are usually the more serious of the two. The effect of these eddies is to cause the magnetic flux, which should be proportional to and in phase with the current in the fixed coils, to lag behind it by an amount depending upon the frequency. In a badly designed wattmeter the error from this cause may easily amount to as much as 10 per cent. with a power-factor of 0·5, and becomes more and more marked the smaller the power-factor, owing to the fact that the eddy-currents lag practically 90 degrees behind the current in the fixed coil, and are therefore more nearly in phase with the current in the moving-coil the greater the lag between current and voltage.

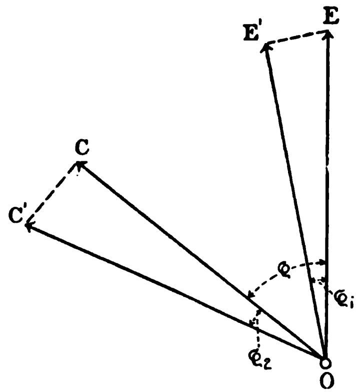

FIG. 16.

The effect of self-induction on the moving-coil circuit and of eddy currents on the fixed field will be more clearly seen from Fig. 16. Let O E and O C represent in magnitude and phase the voltage and current respectively. The power to be measured is equal to O C × O E × cos ϕ assuming a sine-wave.

Owing to self-induction in the moving-coil circuit the current in it will lag by an angle ϕ_1 and let it be represented by O E′, E E′ being the E.M.F. of self-induction. Moreover, owing to eddy currents in the metal parts of the instrument, including the fixed coil itself, the field due to this latter coil will lag behind the current in it by an angle ϕ_2. Let it be represented in the diagram by O C′, assuming the

eddy currents to be in phase with the E.M.F. producing them. Thus the wattmeter, instead of measuring $OE \times OC \times \cos\phi$, actually measures $OE' \times OC' \cos(\phi - \phi_1 + \phi_2)$.

Now it can be shown that if W = the true power and W′ the wattmeter reading—

$$W = W' \left(\frac{\cos\phi_2}{\cos\phi_1}\right) \times \left(\frac{\cos\phi}{\cos(\phi - \phi_1 + \phi_2)}\right)$$

From this expression it is clear that if $\phi_1 = \phi_2$, then $W = W'$. That is to say, that if the lag in the moving-coil due to self-induction is equal to that in the fixed coil due to eddy currents, then the indications of the wattmeter will be correct. This result holds good no matter what be the wave-form, and if the adjustment be made at any given frequency, it will be correct at all frequencies. It is impossible to predetermine the effect of eddy currents, but the induction error is readily calculated. If L = self-induction of moving-coil circuit in henries, R = its resistance in ohms, and $n = 2\pi \times$ frequency. We have approximately—

$$W = W'\left[1 - \left(\frac{nL}{R} \times \tan\phi\right)\right]$$

where ϕ is the angle of phase displacement. To give an idea of the probable error, we may assume a coefficient of self-induction L = 0·02 henry and the resistance for a 100-volt instrument to be 3,000 ohms.

Then at 50 $\sim$ $\frac{nL}{R} = 0{\cdot}0021$.

Hence the percentage error is $0{\cdot}21 \tan\phi$, which gives the following result:—

Power-factor	1·0	0·8	0·6	0·1	0·2	0·1
Error	0·00	0·15	0·28	0·47	1·03	2·00 per cent.

These errors will be reduced in direct proportion to any increase of voltage. Thus a 500-volt instrument will show a fifth of these values.

In any case, the error is seen not to be serious, and, if required, the self-induction can be reduced very much below the value assumed.

Owing to the fact that the field due to the fixed coil is usually enormously stronger than that of the moving-coil, it follows that in certain positions of the latter an E.M.F. is induced in it which is often twenty times as great as that due to the self-induction. It can be shown, however, that it cannot possibly have any effect on the readings. As this point does not appear to have been fully understood, it may be well to enter into the matter somewhat more carefully. In Fig. 17 let O C represent the current, and O E the voltage to be measured. An E.M.F. will be induced in the moving-coil lagging 90° behind the current O C. This is represented in the diagram by O e. Hence the voltage actually available in the moving-coil system is O E′, and assuming the self-induction of the circuit to be negligible, the power measured will be $OC \times OE' \cos a$; but this can be readily shown to be equal to $OC \times OE \cos\phi$, that is to the true power.

The errors caused by external magnetic fields are often considerable, unless the instrument is constructed astatically, and are only to be obviated by taking a second reading after reversing the current in both fixed and moving coils. This precaution should always be taken whether the instrument be used for direct or alternating current. In the former case, the earth's field has often a quite appreciable effect. The stray field error may be roughly determined by short-circuiting the current coil of the instrument, while leaving the voltage on the shunt coil. If a deflection is produced, a corresponding amount (in watts) is to be added or substracted, according to its direction, from the observed power.

For low-current measurements the last method will usually be found sufficient, but for heavy currents the effect of the conductors leading the current to and from the instrument have usually some effect on the readings, and this can only be eliminated by reversing as explained above.

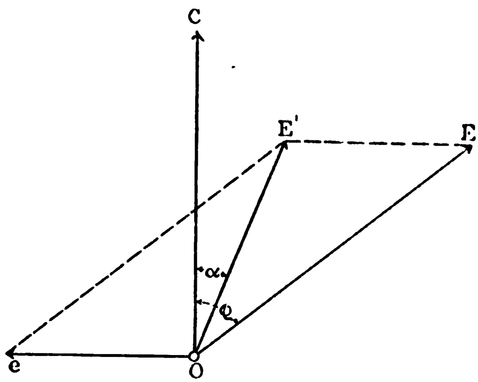

FIG. 17.

Dynamometer-type wattmeters are difficult to construct for currents greater than, say, 200 amperes, as, unless very carefully laminated, eddy currents are produced in the fixed coils, and the effect of the leads just alluded to becomes excessive. In order to increase the range above, say, 400 amperes, or in order to obtain an instrument with more than one current range, recourse must be had either to a series transformer or to a shunt. In both these cases there will be an appreciable phase difference between the current to be measured and that flowing through the fixed coil of the wattmeter. So long as this phase difference is constant, its effect is easily eliminated by so adjusting the self-induction of the moving-coil that the current in it lags behind the voltage by just the same angle as the current in the fixed coil lags behind that to be measured as already explained (Fig. 16). For high-tension working the transformer method is much to be preferred, owing to the fact that the instrument can be entirely insulated from the high-tension system. The power consumption also is considerably less, but for laboratory use the shunted wattmeter is very convenient and somewhat more accurate; though wattmeters with several ranges are seldom so reliable as those with only one.

Induction-type Wattmeters.—These instruments are similar to the induction ammeters and voltmeters already described, the non-inductive coil being replaced by a winding carrying the current, while

the supply voltage is applied to the terminals of the inductive coil. The latter induces a current in the rotating disc or drum which is practically 180° out of phase with the voltage, and as the current coil produces a flux practically in phase with the current, it follows that the torque will be proportional to the product of the instantaneous values of amperes and volts; that is to say, to the true watts. In a similar way the current induced by the current coil reacts on the flux due to the volt coil, and again produces a torque proportional to the true watts.

As was mentioned when dealing with induction ammeters and voltmeters, the indications are much affected by changes of frequency, though almost independent of wave-form.

They are, therefore, chiefly of use for switchboard work, where the frequency is practically constant. For high-tension systems, also, they lend themselves readily to the use of series and voltage transformers.

Hot-wire Wattmeters.—Mr. Michael B. Field* has suggested the use of a hot-wire instrument, provided with a shunt and voltage transformer, as a wattmeter, and although they can hardly be described as switchboard instruments, in that two readings are necessary, we have thought a short description not out of place. Fig. 18 shows the connections in diagrammatic form. T is a transformer connected across the mains through the reversing key K. S is a shunt having a fall of potential of from one to two volts at full load, while V M is the hot-wire voltmeter. It will be seen that in one position of the key K the voltmeter has a tension applied to its terminals which is proportional to the sum of the instantaneous values of voltage and current, and on reversing the key, a tension proportional to the difference of the instantaneous values. Being a hot-wire instrument, the extension is proportional to the square of the voltage, and hence the deflections are proportional to the square of the sum and the square of the difference respectively. It can be shown that if the latter be subtracted from the former, the result will be a measure of the true watts.

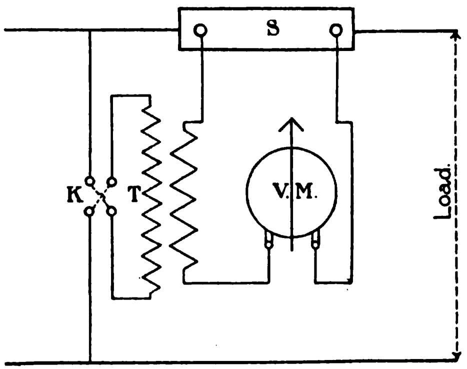

FIG. 18.

The arrangement has the further advantage that it can be employed as an ammeter and voltmeter as well as a wattmeter, and, but for the limitations necessarily imposed upon it by the fact that a hot-wire instrument is employed, the method would seem to have several advantages where a portable instrument with several ranges is required.

* *Electrical Review*, vol. xliii., pp. 767, 811.

METHODS OF CONNECTING WATTMETERS FOR THE MEASUREMENT OF POWER.

Direct Current, or Single-Phase Alternating Currents.

Figs. 19 and 20 show two methods, either of which can be employed. In Fig. 19 the watts spent in the current coil are included in the power measured, while in Fig. 20 the watts taken by the volt coil and its series-resistance are included. The latter method is, as a rule to be preferred, in that the voltage is usually fairly constant throughout a set of readings, and hence the necessary correction can be determined once for all. It is readily found by connecting up the volt coil only, the load circuit being open. The deflection (in watts) so produced has to be subtracted from all readings taken at that voltage. If the connections are as shown in Fig. 19, the correction is found by connecting the shunt coil across the terminals of the current coil when a given current is flowing through the latter, and noting the deflection.

The necessity for applying a correction can be obviated by the simple

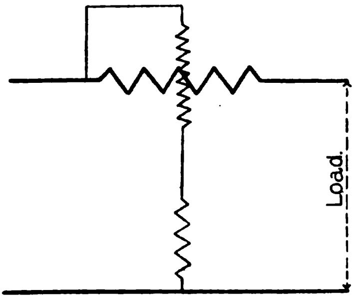

FIG. 19.

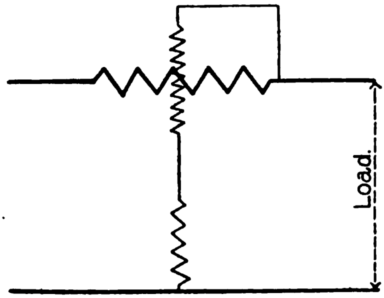

FIG. 20.

expedient of putting a second winding on the fixed coil and connecting it in series with the moving coil in such a way that the current flows through the auxiliary winding in the opposite direction to that in the main winding. If the number of turns of the two coils be made the same, and if the instrument be connected up as shown in Fig. 20, there will clearly be no deflection whatever when the volt coil alone is in circuit, and no correction is necessary.

Two-Phase Systems.—If the load is unbalanced two readings must be taken, the wattmeter being connected first across one phase and then across the other. The sum of the two gives the total power. If the load is known to be balanced, as can be assumed to be more or less the case with motors, it is only necessary to take a reading on one phase and to double it to obtain the total power.

Three-Phase Systems.—If the load is unbalanced two readings are necessary. The connections are shown in Fig. 21, where A and B are either two wattmeters, or the same instrument connected first to one circuit and then to the other. The sum of the two readings gives the

total power supplied to the load. For convenience, the moving coils of the two instruments A and B could be fixed to the same spindle, so that the pointer indicates directly the total power. The question of insulation is, however, a difficult one in a double instrument of this kind, except in the case of low voltage. It is, moreover, necessary, if any degree of accuracy is aimed at, that the two instruments which are connected together should follow precisely the same law; that is to say, that the scales for both instruments should be the same.

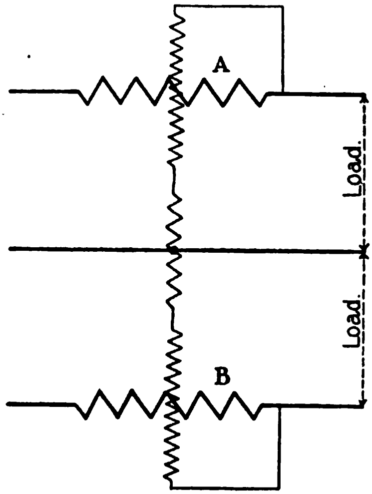

FIG. 21.

With a balanced load a star-connected resistance is arranged as shown in Fig. 22, the arms *a*, *b* (including the moving coil) and *c* are all equal to one another in resistance. The total power will in this case be three times the instrument reading.

PHASE-METERS, OR POWER-FACTOR INDICATORS.

The increasing use of Rotary Converters and Synchronous Motors coupled together with the fact that, by suitably regulating the field of these machines, the idle current in a transmission line can be reduced to zero, has led to the introduction of instruments showing at a glance the lag or lead of the current in the circuit. These instruments can be divided into two classes, according to whether they show the actual angle of phase difference, or merely the wattless component of the apparent power in the circuit. Instruments of the first class can be graduated so as to indicate the actual power-factor of the circuit, instead of merely the phase angle.

If in the ordinary dynamometer wattmeter the voltage circuit be made highly inductive, instead of non-inductive as is usually the case, the current in the moving-coil will lag nearly 90 degrees behind the voltage, so that if the voltage is in phase with the current in the fixed coil, there will be no deflection. The instrument will, in fact, indicate the wattless component of the apparent power.

The first phase-meter to be constructed was of this second type, and was due to von Dolivo-Dobrowolski. It was based upon the induction principle, and was similar to the wattmeters already described, with this difference, that the volt coil was rendered as inductive as possible.

While such an instrument is all that is required to enable the field current to be adjusted to the best advantage, at the same time the actual indications are almost meaningless, so that a true phase-meter is much to be preferred.

The simplest form of phase-meter in the true sense is that shown diagrammatically in Fig. 23. It may be described as a wattmeter having two moving coils rigidly attached to the same spindle and fixed at right angles to one another. One coil (*a*) has a non-inductive resistance in series with it, while that in the case of the other coil (*b*) is highly inductive. These two circuits are connected in parallel across the mains; the current in one will therefore be in phase with the voltage, while that in the other will lag nearly 90 degrees behind it. The fixed coil (*c*) is connected in the main circuit. So long as the current and voltage are in phase the coil *b* will experience no torque, and the coil *a* will therefore turn into the position shown in the diagram. So soon, however, as the current lags behind the voltage, the torque exerted on the coil *a* begins to decrease, while *b* begins to exert an increasing torque, and the moving system takes up a new position, until when the lag is 90 degrees the coil *b* will be in the plane of the fixed coil. This reasoning assumes the one circuit to be absolutely inductionless, and the other perfectly inductive, in which case it can be shown that the deflection of the coil is directly proportional to the angle of phase displacement between current and voltage.

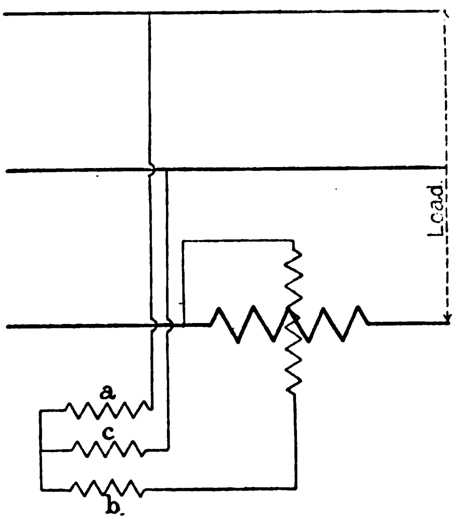

FIG. 22.

In practice, owing to the fact that this assumption is not allowable, the scale is not a perfectly evenly divided one. A little thought will show that, if the current leads instead of lags, the deflection will be in the reverse direction, so that the instrument shows not only the angle of phase displacement, but also whether the current is a leading or a lagging one.

The accuracy of all the phase-meters so far mentioned depends upon the frequency being kept constant. An indicator for three-phase circuits, which is independent of the frequency as well as of the voltage, has been devised by one of the authors. The arrangement is shown diagrammatically in Fig. 24. It consists, as will be seen, of three coils fixed to the same spindle and set at an angle of 120 degrees to one another. One end of each coil is joined up so as to form a neutral point, while the free ends are connected, either through resistances or transformers, to the arms of the three-phase system.

If it is only required to determine the phase displacement in one phase, the current flowing in that phase is led through the fixed coil (*a*), either

directly or by means of a series transformer, and the pointer attached to the moving system indicates the angle of lag or lead, as the case may be, in the same manner as has been already described. Should the average phase displacement of the system be required, two other fixed coils (*b* and *c*), making an angle of 120 degrees with each other and with the coil (*a*) are added. These are each connected in circuit with one of the phases, and the pointer indicates directly the average power-factor of the entire system. It will be further seen that the indications are absolutely independent of voltage, frequency, and wave-form.

The power-factor of any one of the phases can be instantly determined, as already explained, by short-circuiting the other two coils. If they are worked through series transformers it is best to short-

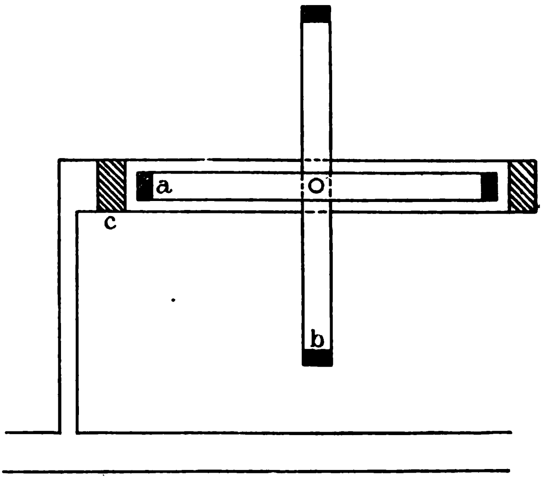

FIG 23.

circuit their secondaries, rather than to open them, as in the latter case the iron will become saturated and the transformer may become hot.

CURRENT AND VOLTAGE TRANSFORMERS.

Allusion has already been several times made in this paper to the use of transformers in connection with measuring instruments. The current transformer is to the alternating-current instrument what the shunt is to the direct-current moving-coil ammeter. It possesses, moreover, some distinct advantages:—in the first place, the power consumed is considerably less, and in the second, the instrument can be absolutely cut off and insulated from the high-tension circuit. The same advantages are possessed by voltage transformers.

The construction of voltage transformers presents few difficulties. On extra high-tension circuits the insulation is the point of chief importance. For this purpose porcelain is by far the most satisfactory

material to use, while above 10,000 volts oil insulation is, as a rule, employed, although Messrs. Siemens & Halske have found it possible to use porcelain insulation for much higher voltage than this.

If the voltmeter in question is to be calibrated direct by comparison with a high-tension standard, no special precautions are necessary in the design of the transformer; but if the voltage-drop at full load be kept low, it is perfectly easy, and in many cases considerably more accurate, to calibrate the voltmeter with the low voltage, and to assume that the primary and secondary voltages are directly proportional to the number of turns in the two windings. The drop of volts from

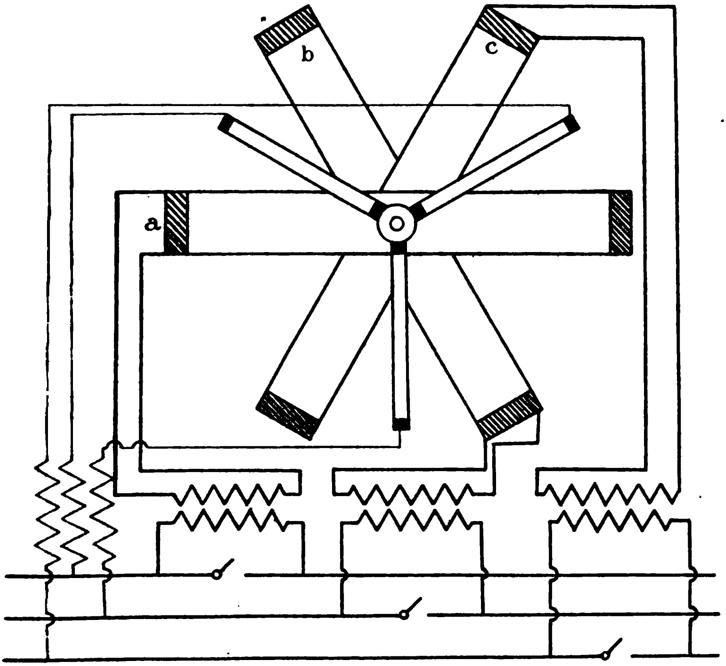

FIG. 24.

open circuit to full load need not in practice exceed 0·3 per cent., so that no appreciable error is introduced from this cause; and it is well known that the ratio of transformation is practically independent of the frequency.

The design of satisfactory current transformers is more difficult, particularly if the indications of the ammeter are to be independent of frequency. With a constant primary current the open circuit secondary voltage will be proportional to the frequency; but if the secondary circuit be a closed one and highly inductive, the current in it will be found to be practically independent of the frequency.* If,

* The effect of frequency can be shown by a simple diagram (see *Electrician*, vol. li., p. 1009).

moreover, the magnetising current be kept small, the ratio between primary and secondary current will be practically constant at all loads. This is, of course, of small importance if the instrument is to be directly calibrated in conjunction with its transformer, but freedom from frequency errors also depends on a low magnetising current.

To sum up, it may be said that to design a satisfactory current transformer the following points must be attended to:—

1. Iron of the highest quality must be employed.
2. The magnetic circuit must be as short and as perfect as possible.
3. The ohmic resistance of the secondary circuit (including transformer winding, connecting leads, and instrument) must be as low as possible.
4. High self-induction, far from being a disadvantage, is actually an advantage so far as independence of frequency is concerned.

The following figures taken from a most interesting paper read by Mr. Albert Campbell before the Physical Society,* illustrate the correctness of these assertions:—

Iron Ring Transformer, Primary consisting of 764 *turns of No.* 16 *S.W.G., and the Secondary of* 48 *turns of* 7/16 *cable. Secondary load a* 100-*ampere Kelvin Balance. Frequency,* 83 *per second.*

Primary Current.	Secondary Current. / Primary Current.
1·0	15·60
1·5	15·67
2·4	15·67
4·1	15·73
6·0	15·69

When the same transformer was connected to a 10-ampere Kelvin balance in which the ratio of self-induction to resistance was much smaller than in the case of the 100-ampere instrument, the ratio was found to vary between 8·12 and 12·28 at the same frequency.

The following figures show the importance of employing a magnetic circuit of low reluctance:—

Ring Transformer connected to 100-*ampere Balance.*

Frequency.	Secondary Current. / Primary Current.	Percentage error from reading at 84 ∿
40	15·48	0·7 per cent.
57	15·52	0·45 " "
84	15·59	...

* *Phil. Mag.*, vol. xlii., p. 271.

In the case of an open-circuit transformer tested under precisely the same conditions, the difference in the ratio between 84 ∿ and 44 ∿ amounted to no less than 24·3 per cent.

The use of current transformers is by no means restricted to high-tension circuits, but is to be recommended for all currents above, say, 500 amperes, if only on account of the great simplification which is possible in the switchboard connections. For currents of 1,000 amperes and upwards the primary winding can be dispensed with, the transformer being simply slipped over the 'bus-bar carrying the current to be measured. In order to avoid the necessity for cutting through the 'bus-bar for its reception, one or two firms have devised transformers in which the core can be taken apart and closed again around the 'bus-bar. In view of the great importance of a thoroughly well-closed magnetic circuit, however, this device seems hardly to be recommended except under exceptional circumstances.

For currents of 2,000 amperes and upwards, the transformers become somewhat large if the magnetic density is to be kept down, and various devices have been introduced with a view to utilising only part of the total current. The simplest consists in cutting the conductor into two parts and allowing only one part to act on the transformer. Messrs. Siemens & Halske have devised an extremely ingenious arrangement, in which the conductor is bent up into a U shape and embraces the secondary coil, which is only influenced by a fraction of a turn. The arrangement has the further important advantage that the coil is unaffected by stray fields.

In conclusion, the authors wish to express their thanks to the various firms who so kindly furnished them with information relating to their various instruments, and in particular to Messrs. The Allgemeine Electricitäts Gesellschaft, Messrs. The British Thomson-Houston Co., Messrs. The British Westinghouse Co., and Messrs. Siemens & Halske. They are also much indebted to Mr. A. C. Nash for valuable assistance in the experimental work connected with the preparation of the paper.

Colonel R. E. CROMPTON, C. B.: I congratulate the authors on their paper as a valuable addition to the proceedings. The paper itself suffers from the authors' perhaps too strict attention to the rules of the Institution—that is to say, they have too little to say as to their own work and to their own methods of constructing their instruments. As a consequence the paper is more a general description of electrical measuring instruments as now made rather than giving us what we should have much desired, the valuable experience which I know the authors' firm has gained in the construction of instruments. This is one of the ways in which papers read before this Institution suffer from the fear authors have of introducing the personal element in their papers for fear that they should be called self-advertising. This is a mistake, and authors should be reassured on this point, as the interest of our proceedings is greatly reduced thereby. Colonel Crompton.

Again, I regret that the authors do not tell us how they deal with many of the difficulties which the users of switchboard instruments are

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continually meeting with. I allude to the fact that, in however good order instruments may leave a maker's works, it is difficult to ensure that they will be accurate and agree in their readings when, after packing, carriage, and corrosion from passing through warm, moist climates, the instruments arrive and are erected at their destination in a state widely different from their condition when tested. On these points a good deal may usefully be said and, I hope, will be added in the course of the discussion.

I therefore propose, as my contribution to the discussion, to give some idea of the methods which my firm have introduced with a view of eliminating these faults, since our system which is open to all, may be the best method of dealing with the inaccuracy so often met with in switchboard instruments, a reproach which is often unjustified, the instruments originally being of excellent quality, but being far from accurate when erected in their places. We therefore suggest, and have already carried into practice, a means by which every electrical engineer who has a switchboard with instruments on it can, at the end of the erection, make certain that he can bring all his instruments to as correct a reading as when they were originally calibrated. In order to do this we provide a set of portable instruments which, for convenience, we have called gauges, by which the engineer can check his switchboard instruments from time to time and adjust them so as to obtain readings in agreement throughout. The matter is, after all, a question of electrical standardisation in which we are now so greatly interested. It seems as if we may in the near future have standard instruments made by varying makers, all of which can be made to give a definite deflection with a standard number of milliamperes or millivolts, as the case may be, applied to their terminals, the deflection being brought from zero to one or two fiducial points, so that in this way the instrument may be made to give exactly the original indications it gave when it was first calibrated at the maker's works. This system of gauging instruments may be applied to several classes, not only to moving coil, but to hot wire, and possibly to other forms.

In order that it may be carried out it is necessary to standardise the manufacture of instruments to such an extent that all instruments made are identical to this extent, that all voltmeters give their full deflection with 15 milliamperes at their terminals, and all amperemetres with 75 millivolts at their terminals. We have chosen these as they are convenient figures, but the final choice must of course be settled by the Standards Committee.

It follows, then, that all that is required in order to ensure that the instruments are brought back to their original readings is that (1) all instruments should be alike when first calibrated, and (2) that they should be capable of ready adjustment, so that when the standard current or pressure is applied at their terminals, as shown by the corresponding gauges, they show the correct deflections at the fiducial points. We find no difficulty in ensuring the first condition. All instrument makers are greatly indebted to Madame Curie for the excellent work she has published in regard to the saturation and persistence of

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the magnetism of steel bars. Madame Curie has pointed out how much depends on the exact temperature to which the magnet steel must be heated before being plunged, and if her directions are closely followed excellent and concordant results invariably follow. The work that she has given to the world in this respect is almost unique in its character and in its accuracy. This accuracy in the production of permanent magnets has been a great boon to instrument makers. Next in importance comes the necessity for extremely accurate workmanship in the pole pieces, the boring of the pole cavity, and the turning to gauge of the core so as to ensure that the annular air-gap is of correct dimensions. I believe that it is possible by suitably devised tools to ensure correctness to within dimensions which mechanical engineers have hitherto thought impossible, such as to differences of little more than one fifty-thousandth of an inch; in fact, I do not think there is any more accurate measure of mechanical length than the field itself gives of the length of this air-gap. Next in importance in making instruments really interchangeable in the points which the authors have mentioned is in the contacts by which the currents enter the moving coil, in the pivot of the coil and in the springs themselves; but it is possible without any great refinement, but simply by well-organised manufacture, to produce sufficient accuracy at these points so that the instruments are practically interchangeable within the ordinary limits of observation. We have found that a great many of the errors which in the authors' paper are put down to electrical causes are really due to want of accuracy in mechanical workmanship. This accuracy is not an unattainable ideal. Once a manufacturer sets himself to organise his plant and tools to obtain accuracy sufficient for the purpose, at the same time he so greatly reduces the cost of manufacture that the present moving-coil instruments can be turned out at prices hardly higher than the moving-iron instruments, which hitherto has been always considered the far cheaper instrument. The result is that the cost of a moving-coil instrument produced with tools of sufficient accuracy is comparatively small, and is not at all a large fraction of the total cost of the instrument when it includes the cases, dials, and other adjuncts.

I have dwelt on this point at considerable length to impress upon you that we have already, by sufficient precision in mechanical manufacture, got over many of the difficulties which have for many years past stood in the way of making instruments sufficiently correct to be interchangeable and so to agree with standards. These difficulties only existed so long as we depended on the personal skill of the workmen who made the instruments, and not on the perfection of the tools with which they are now made. This is an old story as regards the production of repetition work by modern machinery, but in no case are the advantages of it so marked as in the case of turning out moving-coil instruments for switchboard use. Once you have got the instruments so that they are indistinguishable one from the other when brought under the same electrical test conditions, then it becomes an exceedingly easy matter to turn out standard work.

The standardisation of the shunt coils for the ammeters and the

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series coils for the voltmeters is already well understood by any electrical man, so it is unnecessary for me to enlarge upon it.

The gauges I have alluded to, one for voltmeters and one for ammeters, are a pair of well-made instruments, not necessarily better than those on the switchboard, but which for test purposes are only allowed to give a deflection between two stops set so as to give a short range of travel of the needle, so as to reduce the likelihood of the springs being strained or the needles bent by shocks in transit. The instruments that are to be adjusted must have their controlling springs easily accessible and easily adjusted without removing any important part of the instrument. The results have been that we find it is possible to take instruments out of store, fix them on a switchboard, and then take a pair of gauges and adjust them all to the accuracies given in the authors' paper and within an hour after the switchboard is erected.

There is still one point I have not touched upon, on which I should like to hear the authors' opinion, namely, the best methods of providing against the corrosion of the springs and pivots. We have not found it easy to make these of a non-corrodible material, or to protect hardened steel by any lacquer, varnish, or plating so as to give satisfactory results.

Mr Rennie.

Mr. J. Rennie: I should like to bring the discussion back to the paper now before us, because I think there is a very great deal in it that wants talking about, and if it is talked about well the result will be of some advantage, especially to station engineers. First of all, let us direct attention to the fact that the authors set out with the purpose of saying something about instruments that are to be used by station engineers; and in the last sentence on their first page they make a remark which I should like you to look at. They say they have written the paper in the hope of arousing the interest of electrical engineers in this subject—the subject of their own instruments. It is with very great pleasure indeed that one finds on the second page, as the first division of their subject, this paragraph headed "Accuracy," because it seems to me the whole question turns upon the meaning that we attach to that word.

What is accuracy? The authors in one or two places speak about $\frac{1}{10}$ per cent., and in other places they hazard a guess that the ordinary switchboard instruments which they speak of might have an accuracy of a little more than that—five times, they suggest. The question of accuracy is really a question of cost. Greater accuracy means more money; if the station engineer chooses he may have his switchboard decorated with gilt-edged instruments which probably could have a professed accuracy of ·1 per cent., but of what use would it be? Or he might have his switchboard desecrated with instruments that would read to about 5 per cent. They would be cheap, but I suppose he would think them nasty, and they would be nasty. Before we go much further, it seems to me there should be some understanding as to what accuracy is. Is a switchboard instrument to be correct to 1 per cent., 2 per cent., 3 per cent., or what? Certainly it is not required to be accurate to $\frac{1}{10}$ per cent., and as certainly 5 per cent.

should be out of the question. Settle that first, and then the other Mr. Rennie. matters follow. I speak with some feeling in this respect because of the experiences we have at the Board of Trade laboratory. We have instruments sent to us there that sometimes induce remarks which I am afraid the Chairman would not care to hear. They have most extraordinary fittings, and extraordinary questions are asked about them. We have been asked sometimes to give readings to an accuracy of the highest possible for our standards, on an instrument that could be bought for thirty shillings; and I am afraid that with all our skill in writing polite letters, we do not succeed in convincing the senders of such instruments that they are asking for an impossibility. That is one of the reasons why I press so much this question of accuracy on engineers. And since the question is not one for engineers alone, but for station engineers *and* instrument makers, then let these two parties fight it out, settle what is to be a "reasonable accuracy" for this year 1904, and then we shall know what to do with regard to switchboard instruments.

When that is known several other things should follow. I think we should attack the question of terminals—it is just hinted at in the paper: and such things, very important indeed, as the form and structure of scales and pointers will have to be considered. There is an instrument on our walls at the present moment marked with figures ranging from 200 to 700. Those are intended to indicate amperes when the instrument is in use. The station engineer gets a record showing that the reading at a certain time was 425. He is almost certain to get the last igure, no matter who reads the instrument, but what is the value of it? Therefore, I say we want form and structure of the scale fixed; and if were to hazard an opinion—I am neither a station engineer nor an nstrument maker—I would say that scales should all be marked in livisions and not in amperes or volts. With such a scale the person who uses the reading knows the number of the instrument, he knows he constant to apply, and that is all that is wanted. What does the nan reading that 425 do? Do not think this is a trivial thing, because is of the very essence of switchboard instruments. The man reading he 425 sees the 400 mark; each scale division represents a number of mperes which may be anything from 10 to 100. He must decide what his value is and also the ratio of the partition of the scale division nade by the pointer. The 5 may be a quarter of the division, it may e a half, or it may be a fifth. All that has to be done in reading the ointer, which is all the while swinging over perhaps three or four ivisions representing 100 or 150 amperes.

I was glad to see the strong approval which the authors gave to the oving-coil instrument, but I would have liked them to have said a tle more about what seems to me a very important part of that uipment, the shunts. Col. Crompton has spoken about standardising. wish they would standardise the shunts. If you will listen to some rsonal experiences at the Board of Trade, I believe you will agree ith me in the wish that I have sought to convey through Col. ompton to the committee on standardisation. Many years ago we d a shunt submitted which was about 5 ft. long, I think, and

Mr. Rennie. was intended to carry 1,500 amperes, with a drop of 1½ volts. But these heroic dimensions are not confined to the past. Not many months ago we received another shunt, about half as long again—about 8 ft. 6 in. long. The current was very large, 3,000 amperes, and the drop, I think, inordinately large too, 1½ volts.

It is quite an easy matter nowadays to get a good moving-coil instrument which gives its indications perfectly and securely with $\frac{1}{10}$ of a volt drop, and if the instrument makers were pressed a little harder they could no doubt give us even less than that. And the reason why one should press for less and less drop of volts is obvious when you think of the cost of the shunts. The ordinary increase of the electrical industry has induced us at 8, Richmond Terrace, quite recently to enlarge our borders a bit. For the last fourteen years our upper limit of measurement of direct current was 2,500 amperes. We have just lately put in a battery capable of giving a much larger current than that, up to 7,000. We hope to make it 10,000 by and by. We decided that a moving-coil equipment for measurement would be the best; and when we began to discuss the matter with the instrument makers—they are always very good to us, they never hesitate to tell us all their secrets—we found that we were faced with a cost of something like £60 for the 10,000-ampere shunt; the metal alone was comparatively enormous: the size was such that I hesitated, because our establishment is not very large. Such experiences show that this question of shunts must be gone into, and if the Standardisation Committee would only catch the ears of the instrument makers and see what they can do in the way of voltage it would be a good thing. Can they work to $\frac{1}{10}$ of a volt? I believe they can. One of them offered to do it for us. If they can work to $\frac{1}{10}$ let that be standardised for the time, and let us have shunts in accordance. At the opposite extreme, in speaking of the size of shunts, I ought to mention that many years ago we had a shunt submitted as part of an ordinary energy meter which had a resistance of 26½ millionths of an ohm. Its size was about $8 \times 5 \times 4$, all in *inches*, and the maximum load was 4,000 amperes. Some of the students who are experts at figures will be able to tell us the very small drop with which that meter was worked.

There is only one other portion of the paper that I should like to refer to, and that is the very short section devoted to hot-wire instruments. That section might with advantage have been a little longer. We have been lately partially driven to think of this because of the need for measuring large alternate currents, and seeing that the moving-coil indicator is such a very handy instrument we at once said we wanted a dynamometer which would deal with voltages something like $\frac{1}{10}$ of a volt. I do not know, but there may be some in this room now who have got very near those figures already; but however that may be, there is room for something of the hot-wire kind to serve the same purpose. Mr. Trotter, who has not very much time for experimental work, only an odd hour which he can now and again snatch from his other duties, has for several months now been devoting this time (an average of perhaps 2 or 2½ minutes a day) to some experiments on a hot-wire arrangement, and has obtained very good results, showing

that if the matter were pressed it is quite within the range of possibility to get a hot-wire voltmeter which would work with very much less than the one or two volts indicated by Mr. Field's instrument. Mr. Rennie.

I think those are all the remarks I care to weary you with; in the meantime, allow me to thank the authors very cordially for the information they have put on record here. I cordially agree with the remarks which fell from Colonel Crompton with regard to papers on the work of instruments and instrumental methods. It must be remembered that instrument making is now in nearly every case a matter of very exact science. The testing and adjusting laboratories of our foremost instrument makers are in every sense worthy to be classed with any of the well-known standardising laboratories; the work which they turn out is truly scientific work, and the results are worthy of every consideration. It is therefore in my opinion highly advisable, if some method can be devised for bringing it about, that the progress made from time to time in the design of instruments for electrical purposes should be brought before the Institution for discussion. As I take it, our discussions here serve the double purpose of information, and of obtaining what is most invaluable to experimentalists, criticisms from those who are skilled experts in the subjects.

We want to get the instrument users and the instrument makers face to face to discuss these matters. The forms which instruments take and the best way of using them—on these matters nothing but good could come from such discussion; indeed, to my mind, there cannot be good solutions to either unless they are discussed by both the parties. Such discussions could only result in great improvements being effected in the very important subject of measuring in electric lighting and electric power-stations.

Mr. ALBERT CAMPBELL: In the first place let me thank the authors for the very interesting paper they have put before us. To users of instruments, as well as to makers and designers, they have given much valuable information. For example, the designer is much interested in the ampere-turns required in moving-coil instruments (direct or alternating), whilst the user will appreciate the data showing the effects produced by changing temperature, frequency, or wave-form. Some questions of importance have not been touched on by the authors, such as, for example, the magnitude of the deflecting force in the various types of instrument. Mr. Shoults not long ago published an interesting paper on this. Mr. Campbell.

In connection with my system of compensating for temperature, which the authors kindly mention, I should like to make a few remarks. Mr. Rennie suggested reducing the voltage-drop in ammeter shunts. The objection to this is that as the voltage-drop is lessened, the temperature coefficient of the moving-coil circuit has to be increased, as a greater proportion of the circuit must be of copper. With the compensator as actually manufactured the temperature error is negligible with a voltage-drop of 0·075 volt. With regard to "set-up" instruments, of which numbers are now in use on switchboards, could the authors kindly give us some information as to whether in such

Mr. Campbell.

instruments there is trouble due to creeping caused by sub-permanent set?

As to the use of current transformers for measuring large currents, I have on a former occasion before this Institution advocated their use. When visiting the Laboratoire Central, in Paris, last summer, I was interested to find that MM. Iliovici and Janet have made a thorough investigation of the subject, and have found that even with quite small ring transformers satisfactory measurements of very large currents can be made.

Mr. Evershed.

Mr. S. EVERSHED: In their opening paragraph the authors refer to the infrequency of papers on electrical instruments. They rather attribute that to the want of interest taken by engineers generally in this subject. No doubt that is one of the reasons, but I think another equally cogent one is that the subject is very complex, and without covering a vast amount of ground, more than you can cover in a single evening, it is difficult to write a good paper. I think, therefore, the authors are very greatly to be congratulated on having managed to cover so much of the ground as they chose to select in such a very able manner. It seems to me that the general considerations which they give on pages 621–624 could hardly have been done better, and these ought to be very useful indeed to many station engineers. With many of the considerations and opinions which they express, I cordially agree, but, of course, there are many others in which I differ from them. I will, therefore, just run through the paper and note the various points which I think might be commented upon, and give a few figures which no doubt were not available to them, or which they thought hardly of sufficient interest.

The first thing I notice is the question of scales, and the material used for the dial of an instrument. In the early days we all engraved the scales on a metal dial; such scales are practically everlasting, but they are expensive and difficult to produce, and not necessarily very accurate. Another dial that was very common a few years ago was enamel paint, but no mechanical process having ever been devised for putting the marks on the enamel, it was impossible to secure accuracy. Such scales have also the disadvantage that the enamel after a time chips off the metal dial; it is especially liable to do so in a hot engine-room. The result of experience with engraved and enamelled scales is that most instrument makers have adopted paper dials. Of course there was a great deal of prejudice against paper. People thought of newspaper. But a dial of good paper, properly cemented to a metal plate, lasts well under all conditions if it is properly treated; it can be varnished, and the scales can be printed or marked by mechanical processes. Several firms employ a very ingenious instrument, introduced originally by Messrs. Hartmann and Braun, for marking the scales after calibration. With regard to the scales of moving-coil instruments, it is quite true you can get a very open scale in a voltmeter by setting up the spring; and if I may refer to what Mr. Campbell said just now, no difficulty arises from the fatigue of the spring. It is a remarkable fact that a set-up spring shows less fatigue than one which is allowed to go back to zero. I think the principal

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disadvantage of setting up the spring on an instrument to any large extent is that you magnify the errors in the instrument rather faster than you magnify the readings.

The figure given in the paper as the value of the field in the air-gap of a moving-coil instrument, must not be taken as a typical or average value. The figure mentioned is 700. It is possible that in the instruments made by Messrs. Everett-Edgcumbe & Co., the field may have that value, but it does not follow that it is the same in all other instruments of the moving-coil type. In the moving-coil instruments made by my firm, the field used depends on the length of the pointer. With an instrument having an index from 3 inches up to 5 or 6 inches in length, the field in the gap varies from about 1,500 up to about 1,700, whereas in an instrument with a 10 in. or 12 in. index the field would be about 2,200. We have made a large number of instruments with pointers 18 inches long, and in these the field is 4,500. I believe that to be the largest field ever employed in a commercial switchboard instrument. I need hardly point out that the moment of inertia increases rapidly with the length of index and it is therefore extremely important, if you want to keep the period of the movement fairly short, as it should be, to increase the working forces as you lengthen the index. Now in ammeters that can hardly be done in any other way than by increasing the field, and in voltmeters it is desirable to increase the field and so reduce the power consumption. So far as possible I have always attempted to increase the working forces at the same rate as the moment of inertia increases. With regard to the permanent magnets used in moving-coil instruments, in spite of the very valuable work done by Madame Curie, all permanent magnets must be treated in some way to protect them from the various diseases which may attack them in after life. The processes used—for several processes ought to be used on every magnet—have been called "artificial ageing." That seems to me to be a complete misnomer, because it gives a totally wrong impression of what you have to do to the magnet. You might as well say that when you vaccinate a baby you are artificially ageing it! What you have to do with the magnet is to vaccinate it for the various diseases which may attack it. One of those diseases is temperature variation, and therefore you must put it through a process which makes it immune to ordinary variations of temperature. I believe that process is properly carried out by every maker of moving-coil instruments. The next disease which may attack a magnet is natural decay. That attacks a baby also, and no specific has ever been discovered to protect the baby from it. But in the case of the magnet, it is possible by means of appropriate treatment after magnetisation to leave it in such a state that natural decay is practically eliminated. The third disease is one which rather represents sudden death, and that is demagnetisation. Nothing will ever protect a magnet from demagnetisation. If you put a magnet in a field of anything like 100 c.g.s. units, it will be demagnetised, no matter of what steel it is made or how it has been treated. But magnets in moving-coil instruments do not get into fields of that strength, and therefore all you have to do is to protect them against more moderate

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fields of something like 10 or 20, and that can be done with absolute certainty and precision. When those three processes have been properly carried out, the magnet really is permanent, so far as my observations have gone. It is quite true that something depends on the shape. A bar magnet is far more easily upset than a ring magnet, but in moving-coil instruments you do not have to deal with bar magnets. They are all practically closed magnetic circuits.

One of the advantages of a moving-coil instrument from the instrument maker's point of view is that everything can be determined beforehand. You can sit down and make a drawing of it and calculate everything. You can tell exactly what the period of an instrument will be, and the damping, and how long it will take to come to rest, and everything else. But when you come to making large instruments, instruments with indexes something like 12 or 14 inches in length, that is not quite true. You cannot predetermine, at present at all events, the amount of damping due to air-friction against the index. To give you an idea of how important this is, I may say that in an edgewise voltmeter having an index 18 inches long and 2 millimetres in diameter, the damping torque due to the eddy currents of the copper-bobbin on which the coil was wound was 257 dyne cms., while the resistance due to air friction on the index was found to amount to from about 90 dyne cms. up to about 150 dyne cms., dependent upon the extent of the swing; air damping differing, of course, from eddy current damping in that the resistance to motion is not independent of the velocity, and therefore depends to some extent on the amplitude of swing. The next point I noted in the paper relates to the springs used in various instruments, particularly in moving-coil instruments. You will find some figures given on page 626 of the paper for the coefficients of springs. The ordinary spring, which nearly every one uses, is made of phosphor bronze. That has a temperature coefficient of 0·061 per cent. per degree Centigrade, whilst the springs used by the Allgemeine Elektricitäts Gesellschaft have a temperature coefficient of 0·24 per cent.; that is to say, a value approaching that of copper. You would think, at first sight, that every one would use the phosphor-bronze spring because of its low temperature coefficient. Unfortunately, however, the specific resistance of phosphor bronze is between 15 and 16 microhms, while the specific resistance of the Allgemeine Elektricitäts Gesellschaft spring is only about 2·9 microhms, so that what is gained in one way is lost in another, and it does not matter which you use, the elastic constants of the two springs being practically the same. I notice the authors do not like the expression "soft iron instrument"; perhaps that is because a rival maker introduced the term, but it is just as essential that the iron should be soft as that it should move. However, "moving iron" is sufficiently distinctive. The authors refer on pages 636, 637 to the air damper which I devised some years ago. That damper gave me a great deal of trouble at one time, but I do believe it to be about the best form of air damper which has ever been introduced, and for this reason: it solves the extremely difficult problem of providing an air damper which does not add sensibly to the moment of inertia of the instrument.

Mr. Evershed.

If you look at page 636 of the paper, you will find a drawing of a most ingenious air damper, a piston moving in a circular cylinder. Now that damper introduces a very large addition to the moment of inertia of the instrument, and therefore you are obliged to provide a great deal more damping than you would otherwise need. Some time ago I compared the damping due to the cylinder form used by Messrs. Everett-Edgcumbe, and that due to the damper employed in the gauges manufactured by my firm, and I found that whereas with my own damper the decrement was no less than 8·8, that is to say, each succeeding swing was roughly one-ninth the amplitude of the last swing, the decrement of the piston and the circular cylinder was only 2·8, that is to say, roughly, about one-third as much. This has a very important bearing upon switchboard instruments, because it affects the time taken by the instrument to come to rest. The time taken to come to rest in the instrument fitted with my damper was 1·2 seconds; the time taken to come to rest in the other case was no less than 4·5 seconds. But there is another important mechanical difference between these two dampers. The authors tell us that the clearance allowed between the piston and the cylinder—and they tell it with some little pride, and I do not wonder at it, because it is a good achievement—is only $\frac{15}{1000}$ths of an inch. Now in my air-vane damper the clearance all round the vane is $\frac{31}{1000}$ths of an inch; that is to say, more than double. That is a very important point, because naturally a damper which has a big clearance is a more practical thing, and far less likely to stick than one which has very small clearances. As a matter of fact, if I make the air-vane clear the box by only $\frac{15}{1000}$ths, the instrument becomes absolutely aperiodic. I quite agree with what the authors say in regard to the hot-wire instrument, and I think the time is not far distant when it will finally disappear. I have had a long experience with hot-wire instruments, and I have come to the conclusion that the defects in them are inherent, and not due to the design at all. I believe that in future we shall have moving-coil instruments for direct current work, and "soft iron" (or "moving iron") for alternate current work, and that all instruments will have a large decrement. That brings me to the induction type instruments. Some years ago a man came to me with a frequency meter—at least he said it measured frequency. I asked him whether it was affected by variations in the voltage applied to the terminals, and he said, "Yes, it is to a small extent, but still, on the whole, it measures frequency fairly satisfactorily." I did not take up the instrument, because it did not appear to me to be developed into a very practical thing, but curiously enough, that same instrument, designed practically on the same lines, is now being used as an ammeter. It is true that its readings vary with the frequency. The authors tell us that in one case a variation of 50 per cent. in the frequency caused an error of 25 per cent. in the readings, so that you see it is not a very good ammeter and not a very good frequency meter. But still it is a much better ammeter than it was when my friend brought it to me as a frequency meter. Those remarks do not apply so much to the induction voltmeter, because it is possible to make the induction voltmeter read accurately. But as regards the

Mr. Evershed.

ammeter, I am afraid there are almost insurmountable difficulties in the way, inherent again in the principle. The authors said by the way that the temperature coefficient of such instruments is small. It is just possible that lately some device has been introduced to reduce the temperature coefficient inherent in the instrument, but so far as I am aware such ammeters have a larger temperature coefficient than any other type.

Professor Ayrton.

Professor W. E. AYRTON: I have made a great many notes in reading through the paper, but I will be lenient and not deal with them all. I will only touch on one or two points that have not been referred to by any of the previous speakers. I will make my congratulations on the success of the paper short, a subject which has been very wisely referred to by those who have previously spoken.

On page 622 the authors speak about the errors due to stray field, and from that people might be led to believe that those are the sort of stray fields that are met with in central stations; that is to say, the stray field due to 1,000 amperes one metre away from the instrument. This table is extremely consoling to the central station engineers in that it shows that their arrangements do not introduce any serious errors. But a little while ago, doubting that this was the state of things, I had a magnetic survey made of the switchboards of one of the well-known London central stations. It was very easy to do that with our portable magnetic field tester, which some of you are acquainted with. On carrying out that survey, fields far greater than are referred to by the authors were found to exist. Perhaps I ought to mention that 1,000 amperes flowing along an endless circuit a metre away from the point produced a field of about 2 c.g.s. units—the readings made in the survey were also in c.g.s. units, and in some places the magnetic field on the switchboard was as high as 71 units, *i.e.*, 36 times what the authors have referred to in the paper. In many places it was 32 units, and 20 units was quite common at different parts of the switchboard. It is clear, therefore, that what you have to deal with are errors much larger than would be introduced if you only had a field of two units, and you can easily see how that arises. An ordinary switchboard is not more than two metres high, getting on for 7 feet, and supposing one omnibus-bar was quite at the top and the other quite at the bottom, bringing the current back, and each carrying a thousand amperes, there would be in the middle of the switchboard twice the field mentioned in the paper. But, as a matter of fact, in many central stations there are 4,000 amperes, and as the instruments cannot all be in the middle of the switchboard and the mains at the extreme top and bottom, you get fields many times greater than what the authors have referred to.

These disturbing fields are really due to the currents in the conductors, and not due to the dynamos. Last year I had to advise in regard to the disturbance of compasses on ships when large dynamos are used on board, and I had a similar survey made of a modern generating station, but not near the switchboard. These diagrams show the disturbance of lines of force, and the strength of the field near the dynamos when they are running, and not running, and so on. With modern multipolar dynamos, even with large dynamos with an output of some

Professor Ayrton.

hundreds of kilowatts, the field is very small indeed, only comparable with the earth's field, fields of the order of 0·27 and 0·219 not much larger than the horizontal forces due to the earth's field. Therefore the magnetic disturbance in the central station is not due to the dynamos, but is due to the currents in the conductors. As I have just explained, that field may be twenty, thirty or forty times as big as the field which is referred to on page 623 by the authors, and therefore the error may be as great in the same proportion. Hence the statement made on page 627 of the paper that "The ordinary cast-iron case appears to be quite an efficient shield for switchboard instruments" is open to doubt.

I will just refer to one other point in passing, namely, to a difficulty to which the authors quite rightly referred, which I was very much troubled with myself last year, namely, the thermo-electric effect in the shunt when you are using large currents. I had to make some experiments on cables with some thousands of amperes, and that was the difficulty. One of the cables was attached to one end of the shunt, and the other end of the shunt was attached to a small wire. That has been got over by Messrs. Hartmann & Braun, in the following very ingenious way, which is worth mentioning:—

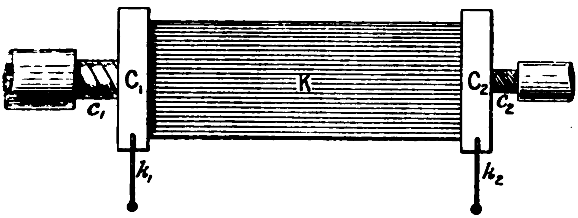

FIG. A.

K is the shunt, made of constantin, C_1, C_2 the copper blocks fastened to it, and c_1, c_2 the copper conductors leading the current into and out of the shunt. Now instead of attaching the copper wires which go to the galvanometer directly to C_1, C_2 or to the ends of K, which may be unequally heated and consequently give rise to a thermo electromotive force, they are attached to two pieces of constantin wire k_1, k_2, which are themselves joined respectively to C_1 and C_2.

I might just mention in passing that the authors said that on page 3 "inversely" ought to be taken away. The "inversely" they have taken away ought to be put into page 640—"the voltage at the terminals of the voltmeter is inversely proportional to the capacities." What, however, I want to refer to, is the combination of the condensers with the electro-static instrument. The authors refer to Professor Peukert originating the method in 1898. Had they had the opportunity of referring to a certain patent specification, No. 20,837 of 1893, they would have found the method described, and claimed as "the combination of a condenser with an electro-static voltmeter for the purpose of measuring very high pressures without the necessity of placing the surface of the working parts far apart."

Professor Ayrton.

I do not allude to this because it happens to be five years earlier than the reference made by the authors, but because on that patent specification there is another claim which is equally important, viz., "the combination of a condenser with an electro-static voltmeter for the purpose of altering the law of the instrument." I do not know whether that has been appreciated, although it is now eleven years old. One of the defects of an electro-static instrument is that the readings are crowded up very much at the beginning and open out at the end. Now if a condenser K of about the same capacity as that of the electro-static voltmeter E.S. be put in series with it, and the P.D. to be measured be applied between the points A and B, this P.D. will divide itself between the condenser and the voltmeter in the inverse ratio of their capacities. Hence when the reading of the voltmeter is low, that is, when the movable needle is not attracted far into the stationary inductor, the capacity of the voltmeter will be relatively low, and much more than half of the whole P.D. between A and B will be maintained between the terminals of the voltmeter. On the other hand, when the readings of the voltmeter is high and the needle is attracted far into the inductor, the capacity will be relatively high, and much less than half of the then value of the P.D. between A and B will be maintained between the terminals of the voltmeter. Hence the effect of this condenser K being in series with the electro-static voltmeter E. S. will be to open out the readings in the lower part of the scale and close up those in the upper part, and consequently make the angular deflection more nearly directly proportional to the P.D. to be measured.

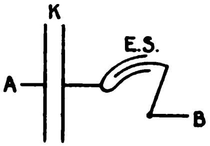

Fig. B.

Going a step farther, to wattmeters, the authors give formulæ on page 646. They say the second one is approximate, but I am not very much in favour of that particular formula, for this reason. The formula in the middle of page 646 would apparently show that the true power was always greater than the wattmeter reading, provided $\tan\phi$ had a positive value and also $\frac{nL}{R}$, that is to say, that with any ordinary self-inductive circuit W must always be less than W′. As was pointed out, however, in this room years ago, that is not the fact. W may be greater than, or less than, or equal to W′, dependent entirely on the ratio of the time constant of the pressure circuit of the wattmeter to the time constant of the circuit, the power given to which would want the measure. It may be equal, greater or less. Further, it does not appear from the formula, but it is important to remember that when $\tan\phi$ is negative, that is to say, when you are measuring the power given to a cable, then W and W′ may differ in sign, and you may get the wattmeter reading negative while the true power is positive.

In fact, if instead of making a confusing approximation, the authors' formula at the top of page 646 be employed, and ϕ_2 be made nought because eddies in the stationary metal are supposed non-existent in this case, we obtain the formula—

Professor Ayrton.

$$W = W' \frac{1 + \tan^2 \phi}{1 + \tan \phi \tan \phi_1}$$

where ϕ refers to the lag in the main circuit and ϕ_1 to the lag in the pressure circuit of the wattmeters.

Now from this form of the formula all that is stated above regarding the relative values of W and W′ immediately follows.*

I have already said that I will spare you, so I will end as I commenced by saying that although I have much enjoyed the paper, and think such a comprehensive *resumé* of our knowledge of instruments most valuable both to instrument makers and others who are concerned in this subject, the lateness of the hour prevents my touching on many other points contained therein.

The President.

The PRESIDENT announced that the scrutineers reported the following candidates to have been duly elected:

Members.

Stanley Clegg.
Archibald R. Dayson.
Frederick J. Evans.

Associate Members.

James Campbell Besley.
Alfred Davis.
Clifford H. Douglas.
Charles Frederic Dyer.
Wm. Whyte Gailey.
Ernest E. Garrard.
Charles László.
W. J. Lloyd.
Geo. Salathiel Maben.
Cyril F. Mackness.
Charles Rodgers.
George Trenbath.
Charles E. Vormeister.
Harold Waring.
Harold Watson.

Associates.

Harry E. Davis.
Harry Geen.
Alfred E. Larkman.
John Meek, Jr.
Sam Pilkington.
William Walker.

Students.

Albert Bothwell.
Wm. Gordon Guns.
Arthur E. Hill.
Gordon C. Kennard.
Franz J. Pescher.
Selden Piercy.
Walter Pintner.
Wm. Ernest Poole.
Samuel P. St. C. Raymond.
Geo. A. Tomlinson.
Percy Weir.

* W. E. Ayrton and W. E. Sumpner on "Alternate Current and Potential Difference Analogies in the Methods of Measuring Power," *Phil. Mag.*, vol. xii., p. 204.

The Four Hundred and Sixth Ordinary General Meeting of the Institution was held at the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, April 14th, 1904—Mr. J. GAVEY, C.B., Vice-President, in the chair.

The Minutes of the Ordinary General Meeting held on March 24th were, by permission of the meeting, taken as read, and signed by the Chairman.

The names of new candidates for election into the Institution were taken as read, and it was ordered that they should be suspended in the Library.

The following transfers were published as having been approved by the Council:—

From the class of Associate Members to that of Members—

William Brew. | Frank Bartholomew Holt.
Alfred Richmond Sillar.

From the class of Associates to that of Associate Members—

James Bennett Bingham. | Albert Edward Short.
Frederick Walter Purse. | William John Unwin Sowter.

Messrs. A. Russell and W. Henderson were appointed scrutineers of the ballot for the election of new members.

Donations were announced as having been received since the last meeting, to the *Library* from Messrs. Constable & Co., J. C. Smail, G. Semenza; and to the *Building Fund* from Messrs. P. Hunter-Brown and A. P. Hutchinson, to all of whom the thanks of the meeting were duly accorded.

The CHAIRMAN: Gentlemen, I have to announce the appointment of a Secretary. As you all know, it has been a very difficult matter to replace our late Secretary by a gentleman of equal energy and equal knowledge. The subject has received the most careful attention of your Council. I am happy to say that we have succeeded in obtaining the services of a gentleman, Mr. George C. Lloyd, who, we hope, will be a fitting successor to the late Mr. McMillan. The Council also, in acknowledging the very efficient manner in which Mr. P. F. Rowell has carried out his duties, have appointed him Assistant Secretary.

There is one other point to which I wish to refer. No doubt many of you will have noticed that Lord Kelvin has been appointed Chancellor of the Glasgow University. We all know Lord Kelvin, and his unique position is such that nothing I might say could raise him higher in your esteem than he stands at present, but there is one point, I think, in which we feel considerable interest. It has been the general practice in the past to confer that high and honorary office on people who have made great names in the political world. We are very happy to find that that office has now been conferred on one who has made the highest name possible in the scientific and engineering world, and, with your permission, it is proposed to write on your behalf to congratulate him on the honour he has received.

ADJOURNED DISCUSSION ON PAPER ON "DIRECT-READING MEASURING INSTRUMENTS FOR SWITCHBOARD USE," BY KENELM EDGCUMBE, ASSOCIATE MEMBER, AND FRANKLIN PUNGA.

Mr. W. A. PRICE: When Colonel Crompton's firm at Chelmsford some years ago took up the question of designing direct-current instruments for the use of central station engineers, they endeavoured to put themselves in the position of a central station engineer, and to produce an instrument in some way which would be especially suitable to his wants. No one will dispute that the first thing the station engineer wants is to have his instruments correct, and if possible to be able to ascertain that for himself and to verify them. The object before the firm was to construct the instrument in such a way that a central station engineer could verify with a considerable degree of precision those instruments for himself, with little difficulty and small appliances. When one begins to analyse the question of switchboard instruments, one at once finds that they divide themselves into amperemeters and voltmeters. Taking the latter first, a real voltmeter of course consists of an indicating instrument in series with a resistance of considerable amount; and in the case of a switchboard moving-coil instrument, in which the current taken by the instrument is so exceedingly small, the resistance becomes correspondingly large. To give an instance of the sort of thing that instrument makers use, a resistance of something like 6,500 or 7,000 ohms would be required for a voltage of 100 volts. If these instruments are to be capable of verification by the users, it is evident that some process of standardisation must be necessary; and one immediately comes to the point that the way in which the thing should be standardised should be that the resistance in series with the voltmeter should bear some definite relation to the pressure to be applied to it, and that the voltmeter should then be looked upon merely as an instrument for measuring the current carried by that resistance. Mr. Price.

Turning to the amperemeter, one knows, of course, that amperemeters all depend on so connecting the indicating instruments that all their resistances which carry the current can be measured. Here, again, one immediately comes to the point that the essential part of this apparatus is the shunt carrying the current to be measured, and that the indicating instrument is nothing but an instrument which

Mr. Price. reads the fall of voltage over the shunt when the current is passing. The system then comes to this: The resistances of the voltmeters and the shunts of the amperemeters are the parts of the apparatus that are standardised. The figures that were selected—they are not important or essential—were that every voltmeter should carry at its normal load 15 milliamperes, and that every shunt should give a difference of potential of 75 millivolts at its full rated load. The voltmeters now become merely milliamperemeters, reading either from zero up to 15 milliamperes, or in the case of an open scale instrument intended to indicate the normal supply pressure, for reading currents in the neighbourhood of 15 milliamperes. So in the amperemeters, all the shunts are merely low resistances giving a voltage of 75 millivolts with their maximum currents, and thus the amperemeter indicating instruments themselves become merely voltmeters indicating the potential difference over the shunts to which they are connected. If this system can be applied, the main parts of the apparatus on which the engineer depends are the voltmeter resistances and the amperemeter shunts. Every instrument maker is able to produce high and low resistances with ease and with certainty, and if these things have been made with proper care, an engineer can depend permanently and with certainty on their retaining their proper values. The only uncertain parts of the apparatus in this case are these indicating instruments which are to be milliamperemeters and millivoltmeters. If an engineer knows that his voltmeter resistances and his shunts have their correct values, that is, are standardised to the loads they have to carry, he is only concerned in ascertaining that the indicating instruments, the milliamperemeters and the millivoltmeters, are in good order. The process of ascertaining whether a millivoltmeter gives the right reading with, say, 75 millivolts, or a milliamperemeter with 15 milliamperes, is an extremely simple operation. In the first place, the whole of it is done with one cell—a Leclanché cell is ample for the purpose—and a simple rheostat. Nothing further is required except a standard instrument of some sort which will indicate with certainty the number of milliamperes and millivolts. It may be said at once that the difficulty of obtaining a standard instrument of which one may be quite certain, is just as great as the difficulty of obtaining indicating instruments for the switchboard of which one can also be certain. But the method of measuring with a standard cell and a few switches and resistances—the whole system which is generally known as the potentiometer system—is so simple that no reliance on standard millivoltmeters and milliamperemeters is required. Having put into the power of the engineer the means of ascertaining whether his instruments are wrong or right, one wishes to add to that a method of setting the instrument right in case of its being wrong. This of course is a purely mechanical problem, and can be solved in thousands of ways, but it will be of interest, I hope, if we could show by a slide on the screen the way in which this has been done at Chelmsford.

The slide (Fig. C) now thrown on the screen shows that part of the instrument which is termed the movement plug. It is a cylindrical piece of iron with brass plugs on the side, which is inserted into a

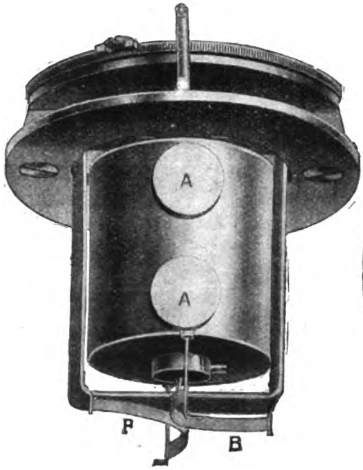

FIG. C.

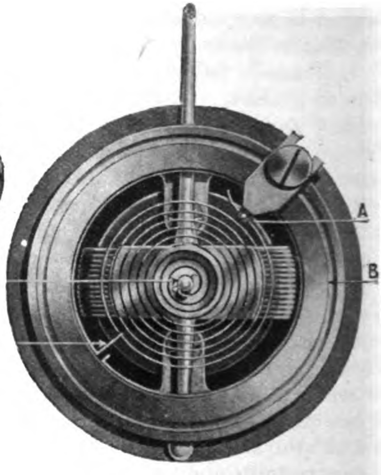

FIG. D.

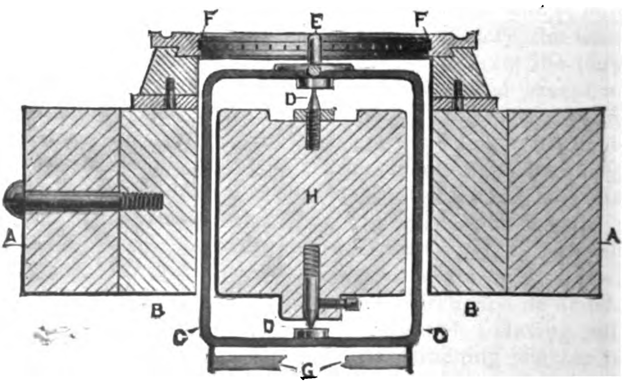

FIG. E.

Mr. Price.

cylindrical hole formed between the magnet poles. The coil is clearly seen, and those thin pieces marked BB at the bottom are ligaments of silver foil which carry the current from pins fixed in the insulating pieces into the movement itself. The next slide (Fig. D) gives a top view of the plug and shows the control spring. From that it will be seen that the controlling springs carry no current at all. The whole of the upper ring to which the letter B is attached is movable and is connected with the part A, the outside end of the controlling spring. The other end of the controlling spring is attached to the pin D which is fixed on the top of the moving coil. The spring passes through a small hole in the sliding ring C. To adjust the zero to its position for any given current the whole ring B can be rotated. To alter the sensitiveness of the spring, that is, the quantity by which the pointer will be deflected by any given current from a given zero, it is sufficient to shift C slightly round in the ring, and so alter the effective length of the spring. The whole of this apparatus is visible from the front of the instrument through a small window or cover which is removable by three screws. The next slide (Fig. E) shows the central section of the whole of the movement. The part marked CC is a moving coil. It is connected to the silver pins by two ligaments marked G. It rotates on two internal pivots, D, AA are the permanent magnet in section, and BB are the steel pole-pieces, and F is the moving ring at the top to which the controlling ring is attached. The whole adjustment of an instrument fitted in this way is performed from the outside of the case without removing the cover or touching the electrical connections.

Mr. Swinburne

Mr. J. SWINBURNE: It is very many years since I had anything to do with instruments, and I beg indulgence if I bring forward matters that are not only old but well known.

Some twenty years ago methods were worked out of compensating for temperature errors by combining wires of different temperature coefficient. Voltmeters and wattmeter coils were thus got out whose ampere-turns were not altered by temperature variations. Wattmeters were also compensated in the way mentioned by the authors. The potentiometer was arranged so that the temperature coefficients of the wires cancelled out with that of the standard cell. By having the arms of a Wheatstone bridge of metals of different coefficients the bridge read in ohms at any temperature. Though these methods are twenty years old, they are never used, so perhaps they are not wanted. Professor Callendar brought the compensated bridge before the Royal Society, and Mr. Campbell has developed the differential wire principle; but otherwise nothing has been done, as far as I know.

The original hot-wire instrument, described about twenty years ago, I think by an American, was compensated. There were two wires, one worked the dial and the other the index. The use of condensers in series in connection with electro-static instruments is, I think, very old, but I doubt if it is very accurate. Leakage in the condenser, instruments, or connections would probably give trouble when such an instrument had been used some time.

The authors say the induction instruments are much affected by frequency. It is over ten years since I worked those out, but my

Mr. Swinburne. recollection is that the frequency error substantially disappears. Such an instrument is always a compromise, and I think the frequency error can be made less than those due to friction, parallax, and so on.*

The induction instrument is interesting, as it will not only work as a voltmeter, amperemeter, and wattmeter; it can be worked also as a phasemeter, to tell the man in charge whether a generator is correctly excited. A wattmeter with a fine wire coil hanging free, and two series coils at right angles, one taking the main and the other the dynamo current, will show whether the dynamo is doing its exact share of the load. An induction instrument can be made to do this even better. One instrument then tells whether the excitation is right; the other whether the steam is correct. Ten years ago, however, it was impossible to induce central station engineers to use such instruments.

Mr. Nalder. Mr. F. H. NALDER: Regarding the soft iron instruments, I would like to emphasise the necessity of using ample control. The type of instrument to which Mr. Edgcumbe has referred in particular is one we had experience of in the early days, and, as compared with more recent types, it is distinctly deficient in control. That is a very important matter indeed when one has to consider the question of instruments being sent to their destination, when perhaps the pivots may get damaged in transit. These difficulties get rather masked when you have plenty of power. The question also arises in Mr. Edgcumbe's paper as to putting soft-iron instruments in cast-iron cases. That may screen them from stray fields to a limited extent, but on the other hand, the cases of continuous-current instruments are liable to become magnetised, and cause a possible error sometimes amounting to 5 or 6 per cent., dependent on the amount of the magnetisation of the case. In regard to the moving-coil instruments, it would be very well if the question had been raised of a standard fall of potential for ammeters. I think Mr. Edgcumbe mentions 0·08 of a volt, and generally speaking, I might say we use that in our own practice. Mr. Price, I think, mentions 0·075 of a volt—there is not a great deal of difference. In the early days, I believe, Weston used 0·03. That meant that there was, generally speaking, a very large temperature coefficient in the instrument. Of course, with the larger fall of potential and the greater control which you are thus able to obtain, there is no doubt that, notwithstanding the increased watts used, there is a distinct gain in using the bigger drop. Mr. Edgcumbe and Mr. Swinburne mention the use of condensers in connection with electrostatic instruments. A case came before me a little while ago where some friends of ours used this arrangement: They had to test a dynamo at double the working pressure—about 13,000 volts. As a matter of fact, they got 20,000, and broke the machine down. They looked for the cause, and found that the capacity of a small condenser which was used in connection with the instrument (which it is very difficult to, at the same time, insulate and screen from causes varying the capacity), was very much modified every time a travelling crane

* Since the discussion I have looked up a test curve of one of the induction instruments, and I find Mr. Edgcumbe is quite right.

passed by, with the result that the instrument was reading 13,000 when actually the pressure was about 20,000 volts. Mr. Nalder.

Mr. LANCELOT W. WILD: I have a few words to say about wattmeters of the dynamometer type for measuring large currents. Instruments of this class can be constructed on three different principles. First, the whole current to be measured can be taken into the instrument. Secondly, the main current can be passed through a shunt, a portion only going through the instrument. Thirdly, the main current can be passed through the primary of a transformer, the secondary current, which can be made as small as we choose, being passed through the instrument. The first method of passing the whole current through the instrument involves the employment of a coil consisting of a conductor of large section. The eddy currents in this coil will cause a lag in the field produced, and consequently errors will be produced when the power-factor of the circuit is varied. Mr. Edgcumbe tells us how these errors may be compensated for adding self-induction to the moving-coil circuit. There is, however, another error produced by these eddy currents which cannot be so easily compensated for. These eddy currents are only another name for the skin effect that occurs in any large conductor carrying alternating current. The distribution of the current in the conductor depends upon the frequency, and the distribution of the field also depends upon the frequency. The moving coil being some distance away from the centre of the conductor, may be working in either a stronger or a weaker field as the frequency is raised, depending upon the design of the instrument. I do not see how this skin effect can be compensated for. It can be reduced by stranding the conductor, but this is difficult to carry out thoroughly with conductors for really large currents. Mr. Wild.

The second method of passing the greater part of the current hrough a shunt is likely to involve still larger errors than the first nethod unless the ratio of self-induction to resistance in the shunt is nade exactly equal to the ratio of the self-induction to resistance of he current coils of the wattmeter. I recently tested a wattmeter with non-inductive shunt. The instrument read correctly on direct current.)n a non-inductive load of 100 periods it read about 30 per cent. low. Vhen the power-factor was reduced to about 0·7 the instrument read ero, and when the power-factor was reduced down below this the istrument read negatively. This shows the sort of errors that are kely to occur. These errors could have been compensated for in ree different ways. First by adding self-induction to the shunt, condly by adding self-induction to the moving coil, and thirdly by lding resistance in series with the current coil of the instrument. ie third method is out of the question, as to reduce the error on 5 power-factor to 1 per cent. it would have been necessary to employ shunt with a drop of potential of 20 volts. With a current of 1,000 peres this would mean a consumption of 20 kilowatts in the shunt. ie other two methods are feasible, but rather difficult to carry out. oreover the amount of compensation being large, the adjustment ist be made with great exactness if the instrument is to be reasonably curate.

Mr. Wild.

I am inclined to think that the third method of employing a curren transformer is the most accurate of the three. The transformer re quires, however, to be carefully designed, otherwise the secondar current will not be in phase with the primary current. The factors to b taken into consideration are the core loss and magnetising current of th transformer, the primary and secondary magnetic leakage, and the rati of self-induction to resistance of the whole secondary circuit. There ar two ways of insuring the secondary current being in phase with th primary. The most obvious and best method is to so design the trans former that the magnetising current and core loss shall be very smal This, however, involves making the transformer rather heavy. Th second method is to so adjust the resistance and self-induction o secondary circuit that the ratio of self-induction volts to CR drop i the secondary shall be equal to the ratio of magnetising current to cor loss current in the primary. Even if the adjustment has not bee properly made, the error on a power-factor of 0·5 can never exceed th amount of the resultant of core-loss current and magnetising current, i the wattmeter has previously been calibrated on a non-inductive load There is no difficulty in making the core-loss and magnetising curren to measure less than 1 per cent. of the total primary current, in which case the error on a power-factor of 0·5 can never exceed 1 per cent., and will probably be much less than this.

Dr. Drysdale.

Dr. C. V. Drysdale : The time this evening is rather short, and I had wished to say something about direct-current instruments; but those have already received, I think, a fair amount of attention and discussion, and I therefore think it would be well if I were to confine my remarks particularly to alternating-current instruments, which perhaps, have not been as much treated, although at the present day they are at least as important as the direct-current instruments Furthermore, they are not so well understood. In the first place, there is a point about the ordinary alternating-current ammeters and volt meters. You will notice that in the paper the authors have referred to the errors which are usual in ordinary soft-iron magnetic ammeters and voltmeters. The authors have also referred in their paper to the com pensation—that is, to the fact that it is possible to compensate ammeters and voltmeters for inductive and frequency errors. There are two ways of doing that—one is the method of using an inductive shunt, and the other is by using a condenser. I have had the opportunity of using instruments made in both ways, and I have to congratulate the authors decidedly upon having obtained extremely perfect compensation in the instruments which they term "Universal." I have put instruments of various kinds under tests with alternating-currents varying from periods up to 200 periods per second, going outside ordinary limits in order to find out what the errors actually do come to. Whereas with the ordinary non-compensating instrument in the ordinary case it may be about 2 per cent.—and I am speaking now of voltmeters in connec tion with which the inductive errors are more serious—whereas the voltmeter may be about 2 per cent. low at 50 periods and about 6 or 7 per cent., or even up to 10 per cent. error at 100 periods, in the authors' compensating instruments they have succeeded in bringing down the

Dr. Drysdale.

100 periods to something of the order of 1 per cent. I have tested also instruments compensated by the condenser method, and though they are not quite as good as that, still I do not know that there is any reason why both instruments should not be very perfect. I think that is a very important point, as the calibrating of instruments for different frequencies is extremely inconvenient, and we must remember, moreover, that instruments having frequency errors will also have wave-form errors. Then there is the very vexed question of alternating-current wattmeters, and I am glad to see the authors have raised that point in their paper. They have at any rate shown that the alternating-current wattmeter is not such a very unreliable instrument as many people have been inclined to consider it. The alternating-current wattmeter is liable to a very considerable number of errors. Nevertheless, if you mly understand what those errors are, there is no difficulty in getting id of them. The authors are to be congratulated on having put these rinciples into practice and having produced a wattmeter which from he tests I have made appears to be fairly accurate at all ordinary poweractors. For some time past I have given some special attention to the lynamometer-wattmeter, and in an article published in *The Electrician*, 1 March, 1901,* put forward what I believe was a pretty closely ccurate explanation of all the errors to which it was liable and of their pproximate amount and methods of elimination. The authors' diagram Fig. 13 requires modification to take into account the capacity which ways exists to a greater or less extent between the different parts of e non-inductive resistance, the demagnetising as well as the crossagnetising effect of the eddy currents, and the reaction of these eddy rrents on the shunt current. The effect of capacity has not been st sight of by the authors, and the remedy of winding the resistance sections is quite effective. It is, nevertheless, well to have as ar an idea as possible of all the phenomena which might occur, as is is of assistance in judging the extent to which they might be minated. For this reason I have drawn two vector diagrams, the st for a wattmeter in which there were no eddy currents, the second which these were taken into account. In Fig. F the wattmeter unt is regarded as having a non-inductive resistance, r_1, shunted by apacity K, which are in series with the coil having resistance r_2 and f-induction L. The total voltage V across the shunt may be divided o two parts, V_1 and V_2, across the non-inductive and inductive istances respectively. Starting with V_1, the voltage across the nonluctive resistance, we have clearly a current V_1/r_1 in the non-inductive istance in phase with V_1 and a current V_1Kp in the capacity, leading . Combining these we get the total shunt current c. If we ltiply the current c by r_2 we clearly get the drop in the second coil : to the resistance, which is in phase with c, and we also have an uctive drop cLp leading the current by 90°. By combining these) voltages, cr_2 and cLp, we get the total voltage V_2 across the inductive l, and the resultant of two voltages V_1 and V_2 is evidently V, the tage at the shunt terminals. The diagram is, of course, extremely ggerated, as otherwise it would be impossible to indicate the various

* Vol. xlvi., p. 774.

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parts. In practice, with any ordinary wattmeter, none of the lines relating to the shunt circuit would differ from one another by more than 1 or 2 degrees, and consequently the only effect of self-induction and capacity is to alter the phase of the shunt current and not appreciably to alter its magnitude. It is easy to show from the geometry of the figure, as I have before done analytically, that the angular phase displacement is $(L - Kr_1^2)p/R$, where R is $(r_1 + r_2)$, the total resistance of the shunt.

The diagram Fig. G shows the modifications that must be made to take into account the influence of eddy currents in the case of other metal parts of the instrument. C, as before, represents the main current, and may also be taken to represent its magnetising force. There is, however, a second usually much smaller magnetic field from the shunt-coil in phase with the current *c*. If the main and shunt coils are approximately at right angles, as in most deflectional instruments

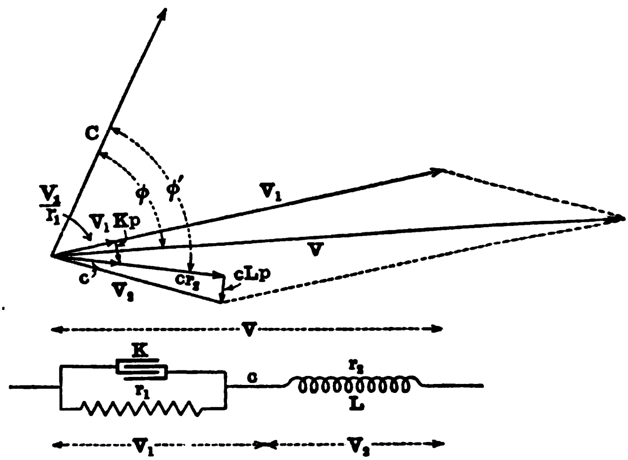

FIG. F.

their fields combine to an elliptical field, but if the coils are parallel, as in the Kelvin watt balance and my own deflectional wattmeter, they will combine to a field as shown in the diagram. This resultant field will produce a voltage, V_3, inducing eddy currents which will lag a considerable amount behind V_3 if in copper, less in brass. The combination of the field, due to the eddy currents with the combined main and shunt fields, gives the resultant field affecting the shunt coil, and which must be perpendicular to V_3. This resultant field, of course, induces an E.M.F., V_3, in the shunt circuit, so that the total P.D. on the shunt will be as shown.

There can be little question that eddy currents should be scrupulously eliminated by avoiding all metal parts but the coils, and laminating or stranding the latter if of any size. The authors' contention that mutual induction between the coils does not affect the reading of the instrument is only correct if the shunt is accurately

Dr. Drysdale.

inductive, otherwise the mutual induction would have a small secondary effect. I do not think any appreciable error can arise from the skin effect or unequal distribution of current in the main coils of a wattmeter if the main coils are carefully stranded. In my own wattmeters, in which the coils could be arranged in various combinations, I have never been able to find any trace of unequal distribution so far as any effect on the shunt coil was concerned. Moreover, I am unable to agree with the last speaker's suggestion to make use of shunts for heavy currents, as I believe that very serious errors would almost inevitably arise. Lastly, as to the suggestions to use transformers in wattmeters, I have recently found that with ordinary small instrument transformers, a phase displacement of 2 to 3 degrees was common between the primary and secondary voltages, and of 10 degrees or more between

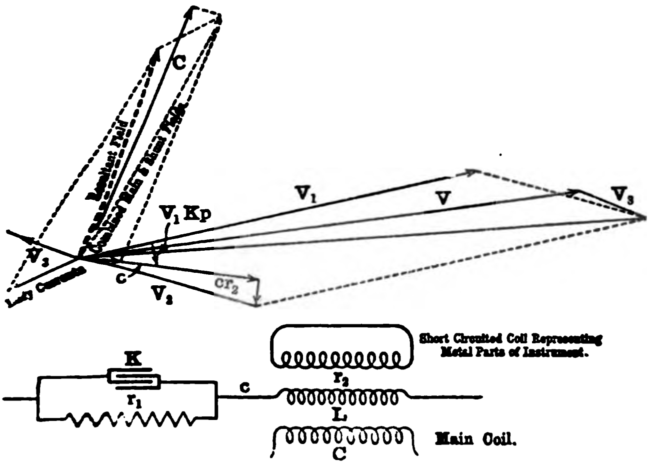

FIG. G.

currents. In the former case, by means of the formula given in paper, which is a slight modification of that originally given by in *The Electrician,* it will be seen that the error in the power-or might amount to more than the total amount of a dielectric loss. conditions for securing accurate wattmeters are exceedingly ple. All metal cases and supports must be avoided—in this respect are in advance of Continental makers—and care must be taken the self-induction and capacity in the shunt do not cause a phase lacement of more than, say, a quarter of a degree. For the user e whether his instrument is correct, he need only try it against dard P.D. and current instrument on non-inductive load at two rent frequencies, or with D.C. and A.C. (eliminating the earth's), and see that it gives no deflection on a circuit of no power-factor. can easily be done when a two-phase supply is available, by ecting the main and shunt coils to the two circuits, taking care the main coil is connected through glow-lamps or other non-

Dr. Drysdale.

inductive load. The correctness of the phase relation between the lines can easily be checked by a voltmeter.

Mr. Vignoles.

Mr. E. B. VIGNOLES: I was inclined to think when I first read this paper that Mr. Edgcumbe was correct in saying that electrical engineers take very little interest in the subject of which he was treating; and I have been somewhat surprised by the floods of eloquence that have poured forth in this discussion.

I should like to point out, first of all, that although Mr. Edgcumbe by the title he has chosen implies that his paper is concerned with instruments for switchboard use, much that he says really applies to instruments which are intended primarily for making very accurate measurements. I should like to draw your attention to the point that it is a complete fallacy to suppose that the primary function of switchboard instruments is to make accurate measurements. Mr. Edgcumbe says, on page 621, "the function of measuring instruments is to measure"; of course it is, but a switchboard instrument is not *primarily* a measuring instrument. Primarily it is an indicating instrument put on the switchboard to enable the switchboard attendant to find out what is happening on his circuits; and in a very large proportion of cases the question of accuracy hardly comes in at all—I mean accuracy in the sense in which people ordinarily use that word. A well-known firm of consulting engineers specifies that for feeders "the ammeters shall be right within 10 per cent." It is a very sensible specification, and I suppose there are more ammeters used on feeders than on anything else in the world. If you consider other circuits, dynamo circuits and so on, it is quite unnecessary to have the degrees of accuracy which are contemplated usually when accuracy of electrical measuring instruments is spoken of. It is generally far more important that the switchboard attendant should be able to see his instruments easily and read them quickly, than that they should be right to 1 per cent.

It is, then, certainly unnecessary in ammeters to go to very great degrees of accuracy (I am speaking now of switchboard instruments), and I very seriously question whether it is of much use in the case of voltmeters. I know that this is not the usual view. The same firm of consulting engineers which specifies that the ammeters on the feeders should be right within 10 per cent., also specifies that the voltmeters should be correct within one volt in 450. Instruments may be made accurate within that amount when they are first put up, but they will not remain like that, as every instrument maker knows. It may be very important to know that all your voltmeters are reading alike; I do not think it is of very great importance to know that they are reading absolutely accurately. So long as you can put your dynamos in parallel with safety, I do not think you need care very much whether the voltage is 600 or 606.

I think, then, that there is no doubt that the primary essential of a switchboard instrument is that it should be visible at a distance; that means that you must have a bold scale with large figures, and it must be of a fairly large size; and that means that you cannot have it extremely accurate. One reason why a switchboard instrument never can

be extremely accurate is one which is not mentioned by Mr. Edgcumbe, but no doubt is in his mind when he speaks of errors of reading. It is parallax. One of the fads in connection with switchboard instruments is, or has been—I believe it is dying out now—whenever you can put in an edgewise instrument to do so. The result of putting in an edgewise instrument is that you get a large parallax error, and you cannot estimate it. Even with instruments with flat dials, when they become big there is a certain amount of parallax error, unless we are very careful to look along the length of the index, which in most cases is not possible, as the tip only is visible. These are the points I wish to make with regard to the general question of instruments intended for switchboard use. Mr. Vignoles

On reading this paper I do not quite know whether Mr. Edgcumbe intended it as a general dissertation, as a treatise on the principles of the construction of instruments. If it is so, I think it is a little too sketchy to be of much use. There are no books, so far as I know, which deal with the subject of electrical instruments thoroughly, and I do not think any paper we have had has done more than allude to the subject in a very sketchy way. I think perhaps Mr. Edgcumbe has intended to draw instrument makers, and he has certainly succeeded in drawing one firm of instrument makers pretty extensively on the subject of the moving-coil type of instruments.

I believe moving-coil instruments are really to be the instruments of the future for switchboard use, because they have a splendid scale and are naturally dead-beat. They can be made interchangeable in the way that Colonel Crompton and Mr. Price have spoken of, and this is advantageous to the manufacturer. Its advantages to the user are more questionable. To secure this interchangeability it is quite unnecessary to bore pole-pieces to $\frac{1}{10000}$ of an inch. If it can be done, which I doubt, it is wholly wasted effort: for the magnets will differ among themselves by large percentages, however carefully made.

Mr. W. DUDDELL: At this late hour I will be very brief in what I say. Mr. Duddell.
will refrain from congratulating Mr. Edgcumbe on his very interesting aper, and devote myself to criticisms. He speaks of hot-wire instruents, and on p. 623 he gives the hysteresis error in hot-wire instruments nil. I am very glad he has found it so; I have not always found them orking with exactly the same precision. Then Mr. Edgcumbe has t noted the temperature zero error. Mr. Swinburne has mentioned mpensated hot-wire instruments; it is very fine in theory, but it is ry difficult in practice to get them accurately compensated; I have ed many methods myself, but I have found it extremely difficult to cceed. I have been working for some time on hot-wire instruments, d hope soon to be able to describe one which will work with a very all P.D. between its terminals. I will refrain from saying anything out wattmeters to-night, as Mr. Mather and myself have been at work them for three or four years past, and have gone into the question the errors in the stranding both experimentally and mathematically. e matter is a very complex one, and when theory seems to suggest t you have got rid of the errors, you find there are still small outding ones. We hope at a future date to bring forward these

Mr. Duddell.

wattmeters which we have at last got down to work well up to 100 amperes.

Moving-coil instruments are probably more used than any other switchboard instruments. Mr. Price referred to the standardisation of the drop of volts, and so did Colonel Crompton. It is a most desirable practice, and is adopted by most of the Continental firms. I have a standard ammeter made by Messrs. Hartmann & Braun some years ago. It is not only standardised for the drop of volts, but it is also standardised for current as well; that is to say, it has a definite resistance. That instrument has a shunt which they supplied me lately out of stock, and it is now, although over four years old, within one-fifth per cent. It is what I call a marvellous piece of work to make a magnet which has kept constant all that time, although often used close to dynamos. The idea of standardising should be carried further than proposed by Colonel Crompton, and the instrument should be standardised both for current and for drop of volts; then you can always make the instrument perfectly interchangeable. If you only standardise the drop of volts without reference to the current, then for very small currents the instruments are not interchangeable. Having seen the design of the coil on the screen, I should like to know what is the temperature error in Colonel Crompton's instrument. There seems to be a little extra copper outside the field—more than there is in an ordinary instrument. I have had great difficulty with low resistances made in England. They seem to vary very considerably. I had trouble with one a little time ago. It went backwards and forwards to the Board of Trade very often, and it is not right even yet. There are one or two clerical errors, which perhaps Mr. Edgcumbe might look into. There is the expression "make and break" on one of the curves which I should like him to explain. In regard to electrostatic instruments, no one seems to have referred to them very much in the discussion. Mr. Swinburne has mentioned the capacity method of sub-dividing the voltage. I think if the condensers are properly designed, so that the insulation resistance of each of the condensers and the capacity are inversely proportional to one another, then you get accurate results, not otherwise. It is all a question of the leakage of the condensers that causes the trouble in sub-dividing. It is to be noted that the capacity of an ordinary electro-static voltmeter is about 10^{-5} microfarad, so that it does not want a very large condenser in order to overcome the error due to the change of capacity of the voltmeter, and the voltmeter is generally shunted by the condenser with the larger capacity. Another point is the question of the spark-gap in the voltmeter. It ought not to be in the voltmeter; it produces ozone or something else, which, after the voltmeter has been in use for a few hours, or a few weeks as the case may be, causes the insulation to go all to pieces.

Mr. Patchell.

Mr. W. H. PATCHELL: Mr. Edgcumbe is in favour of damping. A conscientious supply engineer may strongly object to this. I think if a man goes to the expense of buying a good voltmeter, he does not want the effect of a badly-used motor starting resistance on his mains to be masked by any damping. He wants to know exactly what is

Mr. Patchell

going on on his lines. Of course we may take it the other way. I have had cases of hot-wire instruments which would show periodic swings due to the uneven turning on the engine which the most delicate tacograph which we could get in Europe absolutely failed to detect. But there is a mean between those two points, I believe. As regards power consumed, if Mr. Edgcumbe, on page 623, excludes recorders as switchboard instruments, then I agree with him; but if he says it is of little importance what current is taken by volt-recorders, I absolutely disagree with him. Some years ago, when working with the ordinary Board of Trade section of wire (7/20½, I think it was), we found, with two recording voltmeters on a 3-wire pilot, that if we disconnected one, the other went flying up, due to the 3-wire effect. I got Mr. Elphinstone to go closely into it. I told him our trouble, and that the recording voltmeters which were then available were not good enough, and after some experimenting he got us out an excellent type of permanent magnet volt-recorder. I am sorry Mr. Elphinstone is at present in America and has not been able to put in an appearance here, as few men have done more than he has towards standardising the manufacture of instruments. As regards edgewise instruments, we find them very convenient, as Mr. Vignoles has said, for measuring feeders, and it is not particular in this case exactly how correct they are. We have found, however, that they are more susceptible to stray fields than the flat dial instruments. As regards portable instruments, we had great trouble in keeping our secondary standards correct when we took them into the engine-room to check the voltmeters which I have just referred to as recorders. In those days we were working almost altogether on 2-pole machines, and we had to get a sort of nest of iron coalscuttles and keep the voltmeter inside them with a window through which we read the instrument, and then we found we could take the voltmeter in and out of the engine-room to the laboratory without its standardisation being interfered with. Hot-wire instruments have hardly had fair play, I think. I know of horizontal type hot-wire instruments that were more correct throughout the year than instruments made by either Weston's or Nalder's. I am speaking now of the horizontal type which was due originally to Mr. Evershed. As regards shunts their disposition is important, and it is also important to know what energy is used on them, because if you have several high-current instruments, the heating effect on the shunts at the back of the board is sometimes inconvenient. We have had to go seriously into it, and have got over the effect coming through to the front of the board by separating the shunt from the board by bent copper strips which act as radiators, and by putting the shunts so that their laminæ are vertical and not horizontal as we used to have them. I am very glad to see signs of regeneration on the part of the instrument makers, that they are not wishing now to say that because the instrument has passed their laboratory tests and has a beautiful little bit of sealing-wax with their impression on it, that we must take it as accurate! But I think we must be rather careful before we accept Colonel Crompton's and Mr. Price's instrument; otherwise we may make it too easy for the switchboard man to fake the instruments. These instruments are

Mr. Patchell. very pretty, but the adjustment must not be too easy. Time is getting short, and therefore I will only say that the specimens which I have here are not hot-wire instruments! They are two tested samples of fireproof cable which Mr. Gray said I might show after the last meeting, and I will be very glad to show them to any member after Mr. Field's paper, as unfortunately there is not time to describe them now.

Mr. Kilburn Scott. Mr. E. KILBURN SCOTT (*communicated*): Seeing that there is such a large stray magnetic field near central station switchboards, it does seem rather a waste of time and money to make the instruments so very accurate in the workshop or laboratory. Clearly the thing to do is to remove the instruments from the neighbourhood of the switchboard 'bus-bars, and one way of effecting this would be to have them on the generating unit itself. Steam vacuum and oil pressure gauges and tachometers already form part of the outfit of a large generating unit, so that after all it would not be a great innovation to add an ammeter and voltmeter. All the instruments belonging to each generating unit might be placed together, the dials being such that they could be easily seen from some central point. If this were done a good deal of the switchboard connecting bar would be swept away. Main switches, fuses, and anything to be manipulated must of necessity be placed together, but this does not apply to instruments which have simply to be glanced at occasionally. Of course, in the above, the writer has assumed that the instrument movements are such as to be affected by stray magnetic fields. The hot-wire instrument does not come under that category. When Mr. Evershed spoke so strongly against hot-wire instruments he was, no doubt, thinking of the Cardew voltmeter. It is hardly necessary, however, to point out that the modern hot-wire instruments—such, for example, as the Hartmann & Braun—are as different from the old Cardew as cheese is to chalk. They are especially appreciated for alternating-current circuits and for motor circuits. The perfectly dead-beat quality of the instrument is very valuable for motor work, and this in itself covers any sin of slight inaccuracy, assuming such did exist.

Dr. Garrard. Dr. C. C. GARRARD (*communicated*): As regards high-tension electrostatic voltmeters for switchboard use, I think these may be regarded as satisfactory up to a voltage of 3,000 volts; above this, however, transformer voltmeters alone should be used.

It would appear that the factor of safety (as regards internal sparking) has to be considerably reduced above this voltage, with the result of very frequent breakdowns. When it is remembered that one voltage transformer on a switchboard can generally be used for a variety of purposes (voltmeter, wattmeter, synchroniser, etc.), the cost does not come out greater than that of electrostatic instruments. These latter should always be protected by series resistances. Reference has been made to the series-resistance cut-out manufactured by Messrs. Ferranti, Limited. This arrangement has been tested very thoroughly, shorting a 3,000-volt generator through it, etc., and it has been found to act excellently. In order to get the best results, the resistance of the tube is adjusted for the voltage of the circuit on which it is employed. The following table gives the resistances used :—

Dr. Garrard.

VOLTAGE SUPPLY.	RESISTANCE.
Up to 3,000	... ½ to 1 megohm.
3,000—7,500	... 1 to 2 megohms.
Above 7,500	... 2 to 3 „

These values can be obtained easily by mixing distilled water with tap water, and can be measured by determining the current sent through with an applied voltage of 100 or 200 volts.

Mention has been made of the errors caused in induction instruments by variations of frequency. These errors can be, in the case of ammeters, reduced by shunting the ammeter proper with a non-inductive resistance. I have constructed an induction ammeter, having a torque of 1 gramme-centimetre (for full scale deflection) consuming 10 watts (shunt included), which was quite independent of frequency

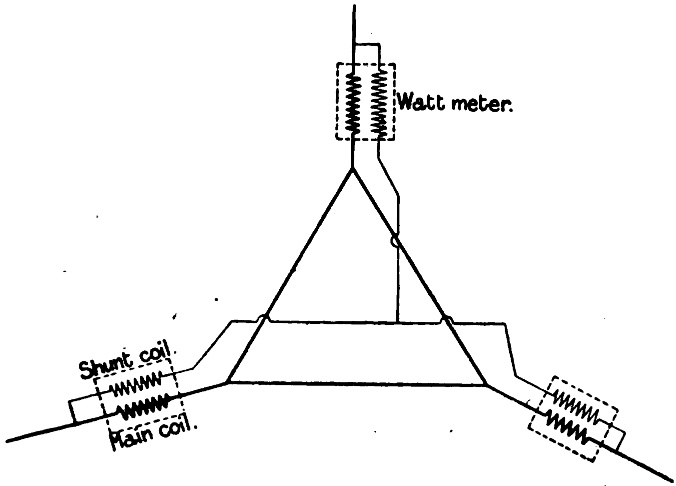

FIG H

tween the limits of 25 and 50 ∿. For switchboard work, however, s does not pay, as, owing to the moving element being necessarily ivy, a higher torque than 1 gramme-centimetre is desirable, and, to ıder this independent of frequency, entails a too large watt-loss. e same method of compensation can also be applied to voltmeters.

In this connection, I would mention that the alternating-current ttmeter recently put on the market by Messrs. Ferranti, Limited, is ependent of frequency over a very wide range.

With regard to the wattmeter connections shown in Fig. 21, this is standard method of connections for two wattmeters for unbalanced hase circuits; it is open, however, to the objection that with low ver-factors, one of the wattmeters goes slower than the other, and below 0·5 one of them actually reverses. It will be seen, therefore, the one meter, considered by itself, is running at a lower power-or than that of the power-circuit. The accuracy of all commercial tmeters, however, decreases more and more the lower the power-

Dr. Garrard. factor on which it is running. Greater accuracy can, therefore, be obtained by the use of three wattmeters. The series coils are connected in the lines and the shunt coils from lines to the neutral point of the system, should the latter be available. If it be not available, the three ends of the shunt coils can be simply connected together as in Fig. H. It may be noted that the accuracy is *not* affected if these shunts differ in resistance or self-induction.

As regards current transformers, the most difficult problem is the design of the transformer for wattmeters. The recommendation of Mr. Albert Campbell that the secondary circuit should have a very high self-induction in order to render the ratio independent of frequency cannot be applied. The only way to render the ratio constant with varying loads and frequency, and to ensure that the phase relationships are not altered by the introduction of the transformer is to keep the magnetising current as low as possible. The primary current is the geometrical sum of the secondary current and the magnetising current. The hysteresis loss of the transformer is so small that it can be neglected. The transformer must, therefore, be so designed that at the lowest frequency on which it is to be used, the ratio $\frac{\text{magnetising current}}{\text{secondary current}}$ must be sufficiently small that the error introduced shall not exceed the greatest allowable. Besides the necessary good magnetic circuit and low ohmic resistance of the secondary, care must be taken that the least possible magnetic leakage of the secondary winding exists.

To increase the self-induction of the secondary winding by making it magnetically leaky would have a bad effect.

With reference to the last paragraph but one of the paper, I would point out that the magnetic density does not necessarily go up with increase of the primary current. If the resistance of the secondary winding of the transformer be kept constant, the magnetic induction goes down. It is easy to see this, as the voltage required to send the secondary current through the wattmeter is constant. The number of secondary turns on the transformer goes up with the primary current. In order that the same secondary E.M.F. may be induced, the induction must, therefore, be smaller.

Professor Marchant. Professor E. W. MARCHANT (*communicated*): I should like to draw attention to one or two points in connection with the "condenser system" method of measuring high potential differences. This method is really a very old one indeed, since in nearly all text-books on electrostatics where the capacity of a number of condensers in series is calculated, it is shown that when a given potential difference is applied to such a system, the ratio of the potential difference between the terminals of any one condenser to the potential difference across the whole, is equal to the ratio of the reciprocal of the capacity of the one condenser to the sum of the reciprocals of the capacities of all the condensers. This, however, is true only on the assumption that the insulation resistance of the whole system and of each condenser is perfect. With constant potential differences the leakage of the charge soon alters the ratio of the voltages.

Professor Marchant.

When alternating currents are used this effect becomes much less important, since the leakages into and out of any one condenser succeed each other very rapidly; the actual value of the insulation resistance necessary to prevent any appreciable difference between the actual and the calculated value has been worked out in the paper by Mr. Worrall and myself, read before the British Association last year.

The first persons, as far as I am aware,* to use the method for alternating-current measurements were Professor Ayrton and Mr. Mather, who suggested (in a patent No. 20,837 in 1893) the use of a condenser in series with an electrostatic voltmeter in order to increase its range. In 1895 Professor Peukert described a special device in which a number of condensers of equal capacity were placed in series with each other, the voltmeter applied to the terminals of any one of them, and the main pressure to the outer terminals. The voltage on the instrument is then $\frac{1}{n}$th of that on the mains, where n is the number of condensers employed. This method (which has been developed by the Allgemeine Elektricitats Gesellschaft Co.) necessitates the use of several condensers of equal capacity, the actual capacity of each being determined by the capacity of the instrument used, since, unless the condensers each have a capacity very large compared with that of the instrument, the total capacity of the instrument and the condenser shunting it will be appreciably larger than that of the condenser alone, and hence the voltage ratio will not be the "capacity reciprocal" ratio of the condensers. Under any circumstance the multiplier could of course be used with a specially calibrated instrument, but with no other. If the capacities are very large compared with that of the instrument, the multiplier can be used on any voltmeter.

The arrangement suggested by Mr. Worrall and myself differs from this in that only two condensers are used, one of which has to have a large capacity compared with that of the instrument with which it is to be used, and which is shunted across the instrument terminals, and the other, placed in series with it, usually a very much smaller capacity. There are many details in connection with the arrangement (some of which are mentioned in the paper, and others have been worked out since) which it would take too long to describe here. I may be allowed, perhaps, to mention one or two of the more important ones. In the series of multipliers now being made by Mr. Paul, a standard shunting condenser is used, and the ratio of the multiplier is varied by altering the capacity of the series condenser. This series condenser has a fixed number of plates, and its capacity is varied by altering the thickness of the dielectric.

The advantage of this arrangement is that the dielectric strain on the material (volts per cm.) may be kept constant for the whole instrument. There are now also in our apparatus special devices for setting the ratio of the multiplier to any exact number and for correcting any small variations.

* At the time of writing the paper for the British Association we had overlooked the work of Professor Ayrton and Professor Peukert.

Professor Marchant.

The various ways in which the "condenser system" principle has been employed are only further evidence of the innumerable adaptations that can be devised, when once a simple principle is understood.

Mr. Edgcumbe.

Mr. KENELM EDGCUMBE (*in reply*):* I suppose it is in the nature of things that it should be said, on the one hand, that too much had been included, and, on the other, that omissions had been made. As no paper on instruments had been read for so long, we thought it best to cover as much of the ground as possible with a view to producing a good discussion, and I feel that our efforts in this direction have been amply repaid. I only wish that central station engineers and consulting engineers could have been persuaded to place their views on record, as, after all, they are the chief users, and, as such, would be gladly listened to. From the extraordinarily small amount of interest which they always evince in the question of measuring instruments, it would almost appear that Mr. Vignoles' contention that switchboard instruments are not intended to measure at all is the correct one.

However that may be, the method of standardisation, described by Colonel Crompton and Mr. Price, is extremely ingenious, and certainly a step in the right direction. The chief point of novelty about it is the fact that the controlling springs are used as the means of adjustment (although this also has been done before), the more usual plan being to employ a variable magnetic shunt. There would appear to be little to choose between the two methods, as the number of magnetic lines shunted can be kept extremely small. The addition of some such adjustment is an immense convenience to the manufacturer as well as to the user.

While on this subject, the question of the drop to be allowed in shunts naturally crops up. Mr. Rennie asks for a twentieth of a volt, and while it may be said at once that it is quite possible to design a fairly satisfactory ammeter working with that drop—and it is often done—yet the same instrument constructed so as to work at one-tenth of a volt will be better, both as regards the magnitude of the available forces and also as to temperature coefficient. The majority of measurements are made with currents of less than 1,000 amperes, and probably below this a drop of one-tenth of a volt is as satisfactory as any other. For larger currents the question of accuracy is, as a rule, of less importance, and a gradually reduced drop can be employed, and for currents greater than, say, 3,000 amperes, a drop of one-twentieth of a volt may be regarded as sufficient.

Mr. Rennie speaks of an ammeter shunt having a drop of 1·5 volts. He is certainly labouring under a delusion if he believes this to belong to a moving-coil instrument. It was, no doubt, intended for use with a potentiometer. For this work a drop of a volt and a half has been selected as a standard, owing to the Clark cell having a voltage of approximately 1·4.

With reference to Colonel Crompton's remarks about corrosion, I cannot say that I have ever noticed this in the case of phosphor-bronze

* In the absence of Mr. F. Punga, Mr. Kenelm Edgcumbe replied briefly on behalf of his colleague and himself to the chief points raised.

Mr. Edgcumbe.

springs, except it was due to a bad flux having been used in soldering. The magnets do occasionally give trouble by corroding on the surface and peeling off, but that is easily got over by painting. As regards the pivots, I am afraid the only chance is to keep the case absolutely air-tight.

Mr. Campbell asks for some figures relative to the controlling forces used in switchboard instruments. This varies so much with different makes and ranges that it is difficult to give even an approximation, but it may be said that the force in an ordinary 6 in. moving-coil ammeter or voltmeter is, as a rule, something of the order of 0·5 gramme centimetres. In a 12 in. scale illuminated dial instrument the force would be perhaps 1 gramme centimetre, while in the case of a recording ammeter or voltmeter the spring might exert a force of even as much as 14 gramme centimetres.

The question of set-up springs has been alluded to by several speakers. There is no doubt that this can be pushed too far. One is, for example, sometimes asked to supply a voltmeter ranging some 20 volts on either side of 500. While this can, of course, be done, there seems no reason whatever for it. A reasonable amount of set, however—as, for example, when the lowest reading is from 60 per cent. to 80 per cent. of the maximum reading—is quite easy of attainment, and the instrument is perfectly permanent. Owing to the fact, moreover, that in a switchboard voltmeter the errors of observation are usually much greater than the errors of the instrument *per se*, increased accuracy is attainable. It is essential that the ratio of length to thickness of the springs should be increased in proportion, as they are more set up. One often comes across instruments in which this ratio is only about one-fifth of that which engineering practice would prescribe, with the result that the straight line law of the spring is departed from.

Mr. Evershed alluded to the use of paper scales, and I quite agree with him that they are by far the most accurate and satisfactory. It would have been interesting had he told us something about the use of predetermined printed scales, which his firm, I believe, use very largely. My own conviction is that it is possible to produce a scale for each instrument from the actual readings in almost as short a time as it takes to adjust the instrument to the predetermined scale, and with, of course, far greater accuracy.

Mr. Evershed takes exception to the term "moving-iron," which we have suggested in place of "soft-iron" or "electro-magnetic." It is perfectly true that the iron must be soft, and also that the instrument is based on an electro-magnetic phenomenon, but the actual feature which distinguishes it from, say, an induction instrument is that the iron moves, so that the term we have adopted seems to us to be quite distinctive, and we are gratified to note that it was employed by many of the speakers in the discussion.

On the subject of air-dampers it should be pointed out that the device shown in Fig. 10 does not necessarily add appreciably to the moment of inertia of the system, as it can be so arranged that the weight of the damper-arm actually counterbalances the weight of the iron and the pointer. In the older instruments of Messrs. Everett,

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Edgcumbe and Co. this was not done, and it is probably to one of these that Mr. Evershed alludes. In the more recent type the moment of inertia is only increased by about 15 per cent. by the addition of the damper, and the instrument comes absolutely to rest in less than two seconds. Further, it is naturally a very easy matter to set the piston centrally in the mouth of the tube, which is all that has to be done so long as the cylinder is set concentrically with the pivot.

Mr. Evershed spoke of extraordinary inductions in the air-gaps; he says, in fact, that in some of his instruments he has gone as far as an induction of 4,500. We have ourselves never come across an instrument with an induction of more than 1,500 in the air-gap. Probably the 700 given in the paper should be taken as the lower limit, the bulk of the instruments measured ranging between 700 and 1,500, 1,000 being a probable average value. We hardly think that a high density in the air-gap is quite a thing to be proud of, except perhaps as a *tour de force*, because it is detrimental to the permanence of the magnet. If an equally satisfactory instrument can be produced with a lower density, then by all means do so; there is no object in increasing it.

In the matter of dependence on frequency of induction instruments, it must of course be at once admitted that they are only suitable for switchboard work where the frequency is fairly constant, but for such a purpose they appear quite satisfactory.

The question of the temperature error in these instruments is somewhat involved, and cannot be dismissed in the simple way suggested by Mr. Evershed, who stated that in the case of the instrument illustrated on page 642 it would be the same as that of copper, viz., 0·4 per cent. per degree Centigrade, and in the case of the instrument on page 643, 8 per cent. per degree Centigrade. In reality, owing to the fact that the torque is proportional to the square of the voltage or current, as the case may be, the former figure is twice as large as it should be. As a matter of fact also, the second figure is some three times too large. Dr. Benischke, to whom this type of instrument is principally due, informs us that he finds the actual coefficient to vary between 0·25 and 0·3 per cent. per degree Centigrade. He explains this apparent discrepancy by pointing to the well-known fact that in the case of an induction motor the starting torque increases with a rise of temperature, owing to the increased rotor resistance.

In connection with Professor Ayrton's most interesting remarks as to the actual fields met with in the neighbourhood of switchboards, it should be noted that the figures given in the paper assume that the instrument is in the worst possible position in relation to the 'bus-bar carrying the current, so that it does not follow that a field, for example, ten times as great as that assumed, will produce ten times the error.

Professor Ayrton alluded to the Hartmann and Braun arrangement for keeping down errors due to thermo-e.m.f. It certainly is very neat, though anything but new. I am told by Mr. Clark Fisher that it was used in Colonel Crompton's laboratory at least ten years ago in connection with their potentiometer shunts, and I know that it has been used in several instances elsewhere. The arrangement of Professor Ayrton of putting an electrostatic voltmeter in series with a condenser is very ingenious

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as a means of opening out the beginning of the scale. I do not know whether it has been much used; I certainly have never seen it, and was not aware of the patent of Ayrton and Mather of 1893, in which they allude to it. Like every true genius, they were before their time. In those days nobody wanted these high-tension voltmeters, so I suppose the matter was allowed to drop. With reference to what was said by Mr. Duddell and others, it is essential that the dielectrics should all be the same; otherwise the reading will depend upon frequency, as the voltages will not simply add up in the ordinary way. When used in series with the ordinary electrostatic instrument, an air-condenser must be used for the same reason. The capacities required are very small, as Mr. Duddell pointed out, and consequently there is no very great difficulty in making a satisfactory condenser having the requisite capacity.

Professor Ayrton objects to one of the formulæ we gave. We said that it was only approximate, but it is far more convenient to use than the accurate formula, which is

$$W = W'[1 - \frac{nL}{R} \tan(\phi - \phi')]$$

$$\text{where} \quad \tan \phi' = \frac{nL}{R}.$$

The inaccuracy is, moreover, extremely small. It amounts, taking the actual figures given on page 646, to $0{\cdot}00044/\cos^2\phi$ per cent., so that at a power-factor of 0·02 the error is less than 1 per cent., and for power-factors greater than 0·1 it is quite negligible.

I did not quite follow what Mr. Nalder meant as regards power. I think the tendency has been rather to increase the power than to decrease it of late years. The power of a modern soft-iron instrument is certainly quite as great as in a moving-coil, and in many cases greater.

Mr. Nalder also alluded to the question of the errors likely to be introduced by enclosing a moving-iron instrument in an iron case. As mentioned on page 635, if the ordinary solenoid arrangement is used the hysteresis error is very much increased, and with it the disturbance due to the magnetisation of the case. In fact, the 5 per cent. or 6 per cent. mentioned by Mr. Nalder is probably a very low figure. In an instrument, however, of the "Universal" type, in which the axis of the coil is parallel to the base, the hysteresis error is quite negligible, and, as regards the magnetisation of the case, it is almost impossible to produce an appreciable effect.

We are much interested to see that Dr. Drysdale bears out the figures given in the paper as to the extremely small frequency error found in the case of the "Universal" ammeters and voltmeters. With an ordinary voltmeter, Dr. Drysdale finds a difference of something like 8 per cent. between an alternating current of 50 cycles and one at [illegible]o cycles, while with the "Universal" instruments he finds it to be less than 1 per cent. It should perhaps be added that these instruments are not compensated in any way, as might be gathered from his remarks, but are merely so designed that the various errors have been reduced to a minimum, as explained in the paper.

Mr. Edgcumbe.

Dr. Drysdale's wattmeter diagram is most interesting, and this is probably the first time that a really complete diagram of what is taking place in a dynamometer wattmeter has been shown. It is, however, considerably more complicated than the one given by us, and for all practical purposes the latter is, we think, sufficiently accurate. The main point of difference is that in our diagram we have assumed that the eddy-currents in the metal parts are in phase, or nearly so, with the voltage producing them.

If Dr. Drysdale finds that they lag by about 45 degrees behind that voltage, then even if the angles of lag in the fixed and moving coils (see page 646) are equal to one another, the wattmeter will read low by an amount depending upon the frequency. We are glad to note that Dr. Drysdale has not been able to detect any error due to change in the distribution of the field produced by the skin effect, as this agrees with the conclusion to which we had ourselves arrived.

The instrument mentioned by Mr. Wild certainly comes as a surprise, as we did not think that at the present day there was any instrument maker to be found bold enough to supply a wattmeter (so-called) worked off a perfectly non-inductive shunt. It is such cases as these which, in the past, have given wattmeters the bad name which they undoubtedly have received.

Mr. Wild makes an interesting suggestion for bringing the primary and secondary currents into phase in the case of a current transformer, viz., by making the ratio of the self-induced volts to the ohmic drop equal to that of the magnetising current to the iron-loss current. The compensation would only be correct, however, at a particular frequency, and the assumption has also to be made that the iron-loss current is in phase with the voltage producing it, which is not strictly true. In our opinion, moreover, it is not of so much importance that the primary and secondary currents should be in phase, as that the phase relation between them should be the same as that between the voltage and the current in the shunt circuit.

Referring to what Mr. Duddell said as to hysteresis in hot-wire instruments, it is hardly necessary to point out that the term "hysteresis" is used in the paper in its ordinary acceptation, viz., as denoting magnetic lag, and this is, of course, absent in hot-wire instruments. Mechanical hysteresis and thermal hysteresis (if these terms may be used) are certainly present to an abnormal extent.

As regards Mr. E. K. Scott's remarks on the "modern hot-wire instrument," it may be safely assumed that Mr. Evershed was actually alluding to these, and not merely to the Cardew instruments, and we must confess that we completely endorse both his and Mr. Duddell's remarks on the inherent inaccuracy of hot-wire instruments. For work such as that alluded to by Mr. E. K. Scott, viz., in connection with motor panels, where accuracy is, of course, of very small importance, a hot-wire instrument is perfectly suitable, although the fact that it is so easily burnt out in the event of a short-circuit is, of course, against it, and in any case it is difficult to see why it should be employed when a dead-beat moving-iron instrument, which will do all that is required, can be obtained at half the cost, and will safely stand a short-circuit.

Dr. Garrard proposes to employ three wattmeters for unbalanced three-phase loads instead of two. This arrangement is, of course, quite as good, except for the extra labour entailed in reading three instruments, but we do not think that his reason for suggesting the alteration is quite conclusive, viz., that they will be working at a higher power-factor than if two instruments only were employed. It is quite true that in the latter case the power-factor on one instrument will be extremely low (the current may be either leading or lagging), but, on the other hand, the second wattmeter will be working at a higher power-factor with this method than will be the case under the alternative scheme suggested by Dr. Garrard. Mr. Edgcumbe.

The CHAIRMAN: Gentlemen, you have already expressed your opinion of Mr. Edgcumbe's paper, so I merely ask you to pass a very hearty vote of thanks for the paper he has been good enough to bring before you. The Chairman.

The vote was carried by acclamation.

The Chairman then announced that the scrutineers had reported the following candidates to have been duly elected:—

Associate Members.

Thomas M. Blackman.
John Hayton Carrick.
Francis W. Cawthorn.
William Crawter.
Robert Hotz.
Arthur P. Hudson.
Joseph G. Leeson.
Edward F. Long.
Benjamin Longbottom.
James C. Macfarlane.
Alexander Murdoch.
Ernest G. Symons.
Alfred J. Todd.
Charles Vernier.

Associates.

George Walter M. Boycott.
Harry F. E. Deane.
William Dingle.
Ernest Edwards.
John Sydney Gardiner.
Frederick P. Griffith, B.A.
William Harrison.
Robert Lindsay.
Guy Stephenson Long.
Herbert S. Pursey.
William B. Pye.
Telford F. Waugh.

Students.

John Curtis.
William H. Glaser.
Harold R. Lloyd.
J. Ambrose Lloyd.
Harry R. Mills.
John G. P. Thomas.
George W. Turner.

The Four Hundred and Seventh Ordinary General Meeting of the Institution was held at the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, April 28, 1904—Mr. ROBERT KAYE GRAY, President, in the chair.

The Minutes of the Ordinary General Meeting held on April 14th were, by permission of the meeting, taken as read and signed by the President.

The names of new candidates for election into the Institution were taken as read, and it was ordered that they should be suspended in the Library.

The following transfers have been approved by the Council:—

From the class of Associate Members to that of Members—

Captain Cecil William Davy, R.E.

From the class of Associates to that of Associate Members—

George Frederick St. Clair Harden.

From the class of Students to that of Associates—

Norman Dyer Field. | William Percival Miller.

Messrs. A. H. Allen and J. T. Haynes were appointed scrutineers of the ballot for the election of new members.

Donations to the *Library* were announced as having been received since the last meeting from Messrs. R. Kaye Gray, Methuen & Co., G. Semenza, and C. Naud; and to the *Benevolent Fund* from Mr. W. Duddell, to all of whom the thanks of the meeting were duly accorded.

The PRESIDENT: Before asking Mr. Merz and Mr. McLellan to give us their paper, in accordance with the Articles of Association I have to announce the Council nominees for the Council for next session. Before reading the list I would like to explain one matter, relating to the Presidentship. The lamented death of Mr. McMillan made your Council think that it would be advisable, in order to have a continuity of policy, that a past-President should be nominated by

them for the office of President, and after some consideration they decided to submit my name for the first half, and the name of Mr. Siemens for the second half of next session. Perhaps in doing this we may be initiating a new manner of election. It is thought that it might be an advantage to the Institution to arrange that the coming-into-office of your President should take place at the first meeting of the session, that is to say, some time in November; and that during the period between the last General Meeting of any session and the first meeting of the succeeding session, there should exist a President and a President-elect. This arrangement has several advantages in the management of the affairs of the Institution which I think you will not fail to appreciate. The old President and the new President would be together for about five months, and the latter would gradually take up the threads of the Institution business, while not being actively engaged in its management, and it is believed this would tend to a continuity of policy. Again, for the Conversazione your Council think it might be an advantage that the invitations should include the name of the President-Elect; the feeling being that the Reception at this meeting could serve as an opportunity for the informal introduction by the President of the President-Elect. I will now read the list of the names of the gentlemen your Council have thought fit to recommend to you as the governors of your destinies for next session:—

MEMBERS NOMINATED BY THE COUNCIL FOR OFFICE, 1904–1905.

As President.

Mr. Robert Kaye Gray.

As Vice-Presidents.

Dr. J. A. Fleming, F.R.S.
Mr. J. E. Kingsbury.
Mr. W. H. Patchell.
Mr. W. M. Mordey.

As Members of Council.

Sir John Wolfe Barry, K.C.B., F.R.S.
Mr. T. O. Callender.
Mr. S. Dobson.
Mr. B. Drake.
Mr. S. Z. de Ferranti.
Mr. J. Gavey, C.B.
Mr. F. Gill.
Dr. R. T. Glazebrook, F.R.S.
Mr. F. E. Gripper.
Mr. J. S. Highfield.
Mr. H. Hirst.
Mr. G. Marconi.
Mr. C. H. Merz.
Mr. C. P. Sparks.
Mr. A. A. Campbell Swinton.

As Associate Members of Council.

Mr. T. Mather, F.R.S.
Mr. Sydney Morse.
Mr. A. J. Walter.

As Honorary Auditors.

Mr. F. C. DANVERS. | Mr. SIDNEY SHARP.

As Honorary Treasurer.

Mr. ROBERT HAMMOND.

As Honorary Solicitors.

Messrs. WILSON, BRISTOWS & CARPMAEL.

If any one has any amendments to propose, I must ask them to be good enough to lodge them within a week from to-day's date.

The following paper was then read :—

POWER STATION DESIGN.

By C. H. MERZ, Member, and WM. McLELLAN, Associate Member.

INTRODUCTION.

Scope of paper.

It is proposed in this paper to discuss some of the salient features of a Station for Power Supply in the design of which station all other considerations are made subservient to the commercial success of the Undertaking as a whole. We do not suggest that the Power Station, as distinct from the Outside System, is the more important section—on the contrary, it should not represent more than 50 per cent. of the total expenditure. It is, however, a simpler matter to compare the details of design and cost of this part of an undertaking with the corresponding part of another than is the case with the outside or distribution system. We shall omit particular reference to the generation of electrical energy either from waste products or by water power—the latter is not of great importance in this country, while the former is in itself of sufficient interest to demand a whole paper for its adequate treatment.

The principles of Power Station design referred to hereafter are applicable to all electricity works, large or small, whether they be designed for Power Supply, Traction, or Lighting, though in small stations some of the considerations may naturally lose force for commercial or other reasons. Power Stations are designed for numerous purposes, from the small station for a town lighting or traction system to the large station for dealing with all the requirements of an industrial neighbourhood; it may therefore be advisable, although the general principles of design are identical, to say at the outset that many of the remarks as to detail which we shall

make apply more particularly to the Power Station (5,000 k.w. or over) of a Power Supply Undertaking—that is to say, of an undertaking whose object is to supply all the requirements (Power, Traction and Lighting) of a district extending over a considerable area.

Essential conditions for commercial success in electricity supply.

The commercial success of such an undertaking is absolutely dependent upon the cheapness and reliability of the supply. It may be urged that this is no new phase of the supply problem; but the argument, though possibly correct in principle, is so wide of the mark in degree that if a station for Power Supply were designed on similar lines to many existing Power Stations for traction and lighting purposes commercial failure would almost certainly result. In the case of a tramway system the capital expenditure on the electrical equipment is not a very large proportion of the cost of the whole system; large sums, therefore, can be, and frequently are, expended on elaborate and ornamental buildings, on highly finished equipment, on the provision of an excessive amount of spare plant, and on unnecessary duplication of auxiliary machinery, without appreciably affecting the commercial success of the system.

In the case of Power Supply, however, there is a limit in price below which a Supply Company must keep if it is to get consumers at all. This limit is low because many large individual consumers are very favourably situated from a power generating point of view, and a Power Company can therefore only attain success by giving due consideration to the factors governing economical production. Reliability of Supply must, however, take precedence over everything else, even over Economy of Production. It is impossible to contemplate interruption of supply to a manufacturer, for if this happens a Power Company has failed in its purpose. To meet this condition involves careful and substantial engineering design and the use of only the best and most reliable apparatus obtainable. It further involves a reasonable allowance of spare plant and renders essential simplicity of design and standardisation of details.

Relative importance of Power Station to Distribution System.

Before entering on the main object of this paper, it may be useful to analyse more closely the relative importance of the Power Station and the Distribution System. Since the early days of the distribution of electrical energy an amount of attention has been directed to the Power Station as compared with the Distribution System which is hardly warranted by its importance from either an engineering or a commercial standpoint. This is no doubt partly due to the fact that it is, so to speak, the mainspring of the whole system, and partly because the merits or demerits of its design are ever open to observation. The importance attached to the Power Station probably accounts for the lavish and unnecessary expenditure which has in many cases been bestowed upon it.* It may be worth while to carry

* When we consider that a boiler only costs £2 or £3 a kilowatt, and a turbine or high-speed reciprocating set £10 at the outside, it is surprising to find power stations running out (as they still do in many cases) to a total cost of £40 or even more per kilowatt. In other words, the mere collecting and joining together of the principal apparatus may cost three or four times as much as the apparatus itself.

the suggested comparison into detail, if only because the conclusions to be drawn materially affect the expenditure on the Power Station itself.

The Distribution System.

(1) The Distribution System of a power scheme will usually consist of a three-phase supply at 40 or 50 cycles per second. We do not refer to the voltage, as this depends to a great extent upon the area covered, and in any case it can easily be transformed. The system of supply having once been decided upon and the cables laid, it is more or less permanently settled for better or worse, and cannot be changed without great expense.

(2) The expenditure upon the Distribution System will probably, in the majority of cases, amount to more than 50 per cent. of that on the whole scheme, especially if the consumer's installation be taken into account. This, whether supplied by the Power Company or not, is really part of the system, in that the Company must bear the expense of any alteration necessary on account of change of system.

(3) The manufacture of cables is well understood, and if they be properly designed and laid they are subject to a very small repair account. A smaller depreciation account is therefore justifiable than in the case of the Power Station.

(4) Large Power Schemes will probably eventually consist of a network of transmission cables, substations, and distributing cables, supplying all the power requirements of a neighbourhood and drawing a supply from more than one power station, the latter being located where electricity is to be obtained most cheaply from either coal or waste products.

(5) The Distribution System has a comparatively high efficiency, probably not less than 75 per cent.

(6) On account of the high initial cost of installing the Distribution System, in taking up ground, etc., and the difficulty of making small beginnings and economically adding to them hereafter, the Distribution System should be, and generally is, put down with more margin for future requirements than is the Power Station.

The Power Station.

On the other hand—

(1) A Power Station has a comparatively low efficiency, not more than 10 per cent.; there is thus room for large improvement in the generation of power. For this reason the depreciation account must necessarily form a much higher percentage of the capital cost than in the case of the Distribution System.

(2) A Power Station is capable of easy extension without affecting in a very marked degree the ultimate cost. It can therefore be begun on a smaller scale.

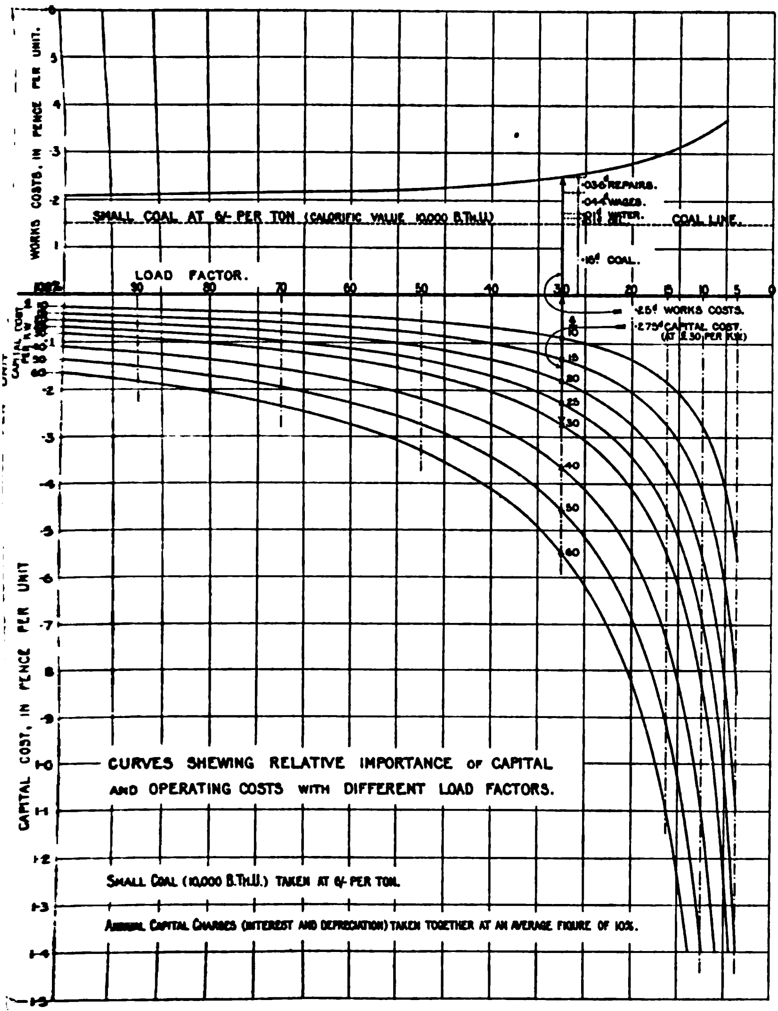

WORKS COSTS, IN PENCE PER UNIT.
CAPITAL COST, IN PENCE PER UNIT
SMALL COAL AT 6/- PER TON (CALORIFIC VALUE 10,000 B.TH.U.)
COAL LINE.
·036d REPAIRS.
·044d WAGES.
·01d WATER.
·16d COAL.
LOAD FACTOR.
·25d WORKS COSTS.
·275d CAPITAL COST. (AT £30 PER K.W.)
CAPITAL COST PER K.W.
CURVES SHEWING RELATIVE IMPORTANCE OF CAPITAL AND OPERATING COSTS WITH DIFFERENT LOAD FACTORS.
SMALL COAL (10,000 B.TH.U.) TAKEN AT 6/- PER TON.
ANNUAL CAPITAL CHARGES (INTEREST AND DEPRECIATION) TAKEN TOGETHER AT AN AVERAGE FIGURE OF 10%.

FIG. I.

(3) It may pay in the future to change even the location of the Power Station, and to feed the system from some other site or sites where energy can be more cheaply generated.

The principles of Power Station Design.

It is essential for the designer to keep before him the two main considerations, "Reliability of supply" and "Economy of production." The latter may be conveniently subdivided into Running Charges and Capital Costs. Early engineers, whether civil, mechanical, or electrical, were justifiably content if the work for which they were responsible proved reliable, Operating and Capital Costs being minor considerations. The necessity for low operating costs was next fully recognised, so much so that this consideration was allowed to overrule all others, even that of reliability—certainly a backward step. The fact that a project must work well and efficiently, and that it must do both of these with a minimum of initial expenditure, is now realised as essential. No engineer can afford to disregard *low capital cost*, which is equivalent, commercially, to *low annual cost*. The importance of keeping the capital cost as low as possible, especially in the case of the Power Station, may be fully appreciated by a careful consideration of its characteristics as referred to above. We do not think it is wide of the mark to suggest that 10 per cent. per annum should be considered as sinking fund in deciding whether to spend more money than is absolutely necessary on any particular section of the plant in a Power Station in order to secure lower running costs. In stating this we have specially in mind the liability of change in the generation of power, both in method and in the location of the Power Station. The relative importance of Capital Cost and Running Cost may be seen at a glance for any particular values of either load factor, capital cost, or running cost, from the curves attached. (See Fig. 1.) From these curves it will be seen that a reduction of the capital outlay by £1 per k.w. has a greater effect on the running costs than has a reduction of the coal bill by 6 per cent.* This applies with a load factor as high as 30 per cent.; it is therefore evident that for lower load factors the question of limiting Capital Expenditure becomes of overwhelming importance as compared with that of reducing Running Costs.

There are one or two general principles which it may be worth while to discuss, each having special reference to Reliability of Supply and Economy of Production. They are :—

(1) Simplicity of design.
(2) Sub-division of plant and apparatus.
(3 Labour-saving devices.
(4) Provision for extension.

Simplicity of design.

(1) *Simplicity of Design.*—Simplicity of design is desirable apart from (as well as on account of) the question of economical production, and generally speaking, it may be accepted that no complications introduced to facilitate the repair of a breakdown are justified should the complications themselves increase materially the risk of breakdown.

* On the basis of coal at 6s. per ton.

That all the earlier station engineers should consistently disregard this axiom was perfectly natural, as, in view of the comparatively unreliable apparatus at their disposal, they were more impressed by the necessity of speedy repair than by the importance of avoiding a breakdown altogether. In fact they came to regard breakdowns as inevitable, devoting their attention to minimising their effect rather than to reducing the amount of apparatus in which a breakdown could occur. This line of procedure, while possibly justifiable in the earlier stages of the industry, has in many cases been pushed too far. In some stations the designers have apparently set themselves the task of rendering possible every conceivable combination of pump and boiler, boiler and engine, generator and exciter, etc. Ten years ago Mr. Ferranti actually practised this doctrine of simplification, more especially with regard to the electrical side of the station, and as an example of its systematic and logical application the general arrangement of a Ferranti single-phase board is unsurpassed.

In the design and general arrangement of the mechanical portion of the station equipment the complication which formerly existed now appears to be diminishing. For instance, at one time a ring steam main was considered necessary, but it was speedily realised that the inherent objections were very numerous, most engineers returning to the sub-divided straight main into which all boilers fed and from which all engines drew their supply of steam. Fortunately cases of a burst steam pipe in a station have been rare, but the failure of a pipe or valve at full load anywhere near the middle of a main would probably result in shutting down the whole station, whether a ring main be used or not.

Sub-division of plant and apparatus.

(2) *Sub-division of Plant and Apparatus.*—The only way to remove all risk of a complete shut-down due to the failure of a steam pipe is to sub-divide the boiler-house plant into a series of groups, each group having no connection with its fellows.* In fact it is now considered imperative in a large power station to sub-divide all parts of the apparatus from the boiler-house to the switchboard into a series of units, each complete in itself. This is certainly essential to Reliability of Supply, and it is in no way inconsistent with Economy of Production. From the point of view of Reliability of Supply, if trouble is to be had with anything it will be obtained by crowding together all kinds of water and steam pipes in one trench. If trouble is to be had with auxiliary apparatus, it will be obtained by locating it with other apparatus, and not sub-dividing it properly. If trouble is to be had with switchgear, it will be obtained by fixing many cables or connections for different purposes, either on one panel, or in one partition, or in one cable trench, as the case may be.

Labour-saving devices.

(3) *Labour-saving Devices.*—It is sometimes justifiable to disregard the question of economical production on account of the difficulty of obtaining labour, especially intelligent labour, at a reasonable price. To obtain suitable labour becomes more and more difficult every day,

* When the initial capacity of a station is comparatively small and a cross connection is considered desirable it should be made through a length of pipe having stop valves at each end.

not (we hope) because the supply grows less, but because the demand increases faster than the supply. This matter is specially referred to, as the authors have found it difficult to justify the inclusion of a great proportion of labour-saving apparatus by any actual calculation of possible economies in capital or running costs. Take even the ordinary mechanical stoker; we doubt very much if, taking into account first cost and repairs and also efficiency, this is in practice justifiable except in order to meet the labour difficulty. Certainly in the case of most coal-handling plants it will be found that the cost of labour saved is more than counterbalanced by the charges for interest, depreciation, and repairs on the elevating and conveying apparatus. We have known a case in which the capital and repair charges exceeded by 200 or 300 per cent. the economy in wages—there obviously the expenditure was not justified.

Before expending money in labour-saving devices the *pros* and *cons* of the case should be systematically considered. On the one side should be put capital charges, taken at not less than 15 per cent. of the capital cost, and repairs—the latter to be estimated. On the other side should be put the saving in labour. The expenditure may be justified if the two sides balance, not otherwise, unless, of course, the case be qualified by the existence of special labour difficulties. Incidentally it may be remarked that the adoption of labour-saving apparatus may either increase or reduce Reliability of Supply. It will increase it in so far as the human element can be safely replaced by automatic machinery. It will reduce it, due to the absence of any one to look after it or to take its place should it break down, if the apparatus installed be too complicated.

Provision for extension.

(4) *Provision for Extension.*—Frequently in the design of a traction station engineers have considered it sufficient merely to provide for immediate requirements, or to arrange the station so that it is capable of extension to a certain definite number of additional units of specific size only. In stations essentially for the wholesale supply of power this does not seem sufficient. Not only are future requirements unknown, but it is difficult to foresee the type of plant which it may be advantageous to instal in the future. For instance, a station made for half a dozen reciprocating sets would provide accommodation for three times as many turbines, in which latter case a difficulty would be met with in providing boiler space with reasonable lengths of steam piping. This is a difficult matter to deal with; not only has one to consider the use of turbines if they are not installed in the first instance, but to make a choice of the different types of turbine, vertical and horizontal, and to consider the further possibility of adopting gas engines later.

Effect of extension on capital cost.

Power Stations for wholesale supply, if the eventual capital expenditure per unit sold is to be kept down, must not be designed for to-day. There is nothing which increases the station capital account so rapidly, and prevents that gradual decrease of capital expenditure per unit sold which should take place with the growth of a system, as alterations to existing work and rearrangements in order to meet increased output. It is possible in laying out a station to avoid placing chimneys,

flues, offices, and elaborately built brick ends so as to interfere with extensions to either boiler-house or engine-room, though it is to be feared that this is not always done. In deciding upon general arrangements, therefore, or the position of any particular piece of apparatus, or the size of any pipe or trench, it is essential to consider whether such decision is likely to affect (or to be affected by) future extensions.

Having referred to the main principles governing Power Station design, we shall proceed to discuss some of their effects on actua design, on the assumption that the Power Station under consideration is for the supply of energy as Three-phase High Tension current at 5,000 volts or over. To illustrate discussion we make frequent reference to certain designs for which we, as Engineers, are responsible, our justification for this course being that we are necessarily familiar in these cases with the reasons governing the detail design and the choice of apparatus.

(I) TYPE OF GENERATING PLANT.

Influence of type of plant on general arrangement of Power Station.

Although the general design of the main building should permit of any type of plant being used for extension, it is obviously necessary to settle on the type to be adopted in the first instance before proceeding with the detail design of any portion of the structural work. While, therefore, it would appear the natural sequence to deal with the buildings and general arrangement before discussing the generating plant, we propose in this paper to adopt the course which would be followed in actually designing a generating station, and to discuss first the relative merits of various types of prime movers. The most convenient way of doing this is to consider them in the order of their development, viz. :—

(1) Slow Speed Reciprocating Engines.
(2) High Speed Reciprocating Engines.
(3) Steam Turbines.
(4) Gas Engines.

Reciprocating engines.

Comparisons have been so frequently instituted between the first two types and their relative merits so thoroughly discussed that it would serve no useful purpose to carry the discussion further. Before, however, proceeding to group together slow and high speed reciprocating engines to compare their merits with those of the turbine, we will briefly touch on their chief characteristics. High speed apparatus should obviously for the same power cost less than slow speed. It will, moreover, take up less room. On the other hand, the advocates of slow speed engines claim that the repair bill of a high speed engine is higher, and the economy not so good as in the case of a slow speed set. It is only in this country that the question as between the two types has arisen at all—neither on the Continent nor in the United States has any progress been made with high speed apparatus, and the perfection to which high speed engines have been brought in this

country is all the more creditable in view of relatively slow progress in some other branches of the industry.*

Steam turbines.

Every year steam turbines claim increasing attention.† They have already been adopted for the largest new stations in this country, on the Continent, and in America. Opinion is, however, still divided with regard to their merits, and we are therefore, perhaps, justified in dealing with the question at some length. The present position of steam turbines may be said to be almost entirely due to the indefatigable energy of the Hon. C. A. Parsons, who has laboured many years on their development. A Swedish Engineer, De Laval, has also been engaged on the subject for nearly, if not quite, as long. His turbine, however, runs at so high a speed (10,000 revolutions per minute) that it is impracticable except in comparatively small sizes. Of turbines‡ more recently placed on the market the best known is perhaps the "Curtis," § which has been developed by the General Electric Com-

* See *Proceedings of the Institution of Civil Engineers*, vol. cli.: "High Speed Electrical Generating Plant," by T. H. Minshall. According to figures recently published high speed engines have been built with a consumption of only 16 lbs. of water per kilowatt hour (steam at 200 lbs. and 200° F. of superheat)—which figure will bear comparison with the very best slow speed results.

† See paper before the Municipal Electrical Association: "Steam Turbines," by S. E. Fedden, July, 1902. Also "Some Notes on Steam Turbo-Electric Generating Plants," by Geo. Wilkinson, before the Leeds Local Section, Institution of Electrical Engineers, October, 1903.

‡ The only Turbines of large size which have been running any considerable time are those of the Parsons type made by C. A. Parsons & Company, though the Westinghouse Company and Messrs. Brown Boveri (who manufacture the Parsons Turbine under license) have also started up some large turbines within the last eighteen months. The following table gives a few particulars of the various types of steam turbines :—

Type.	Output k.w.	Speed r.p.m.	Approximate peripheral speed in ft. per second	Expansion Stages.	Total Number of rows of blades.	General Characteristics.
Parsons ..	1,500	1,200	100 to 220	Continuous.	78	Drum construction—fall of pressure equally divided between stationary and moving blades.
Rateau ..	1,500	1,200	150 to 250	25	25	Disc construction—fall of pressure occurs only at nozzles in stationary discs.
Curtis ..	1,500	1,000	400	4	8	Disc construction—arranged vertically, two rows of revolving blades to each set of expanding nozzles.
Stumpf ..	1,500	3,000	1,400	1	1	Expanding nozzles, single disc, buckets similar to Pelton Wheel.
De Laval...	200	10,600	1,400	1	1	Expanding nozzles, single disc, drives dynamo through helical gearing.

§ See *Proceedings of the American Philosophical Society of Philadelphia*, April, 1903. "The Curtis Steam Turbine," by W. L. R. Emmet.

pany of America. Other types are the "Rateau,"* manufactured by the Maschinenfabrik Oerlikon, Zurich, and the "Stumpf," developed by the Allgemeine Elektricitäts Gesellschaft, Berlin. In addition to these there are various modifications of the Parsons Turbine manufactured by different firms.

Advantages of Steam Turbines.

Whether the final form of turbine will be of the Parsons type, or whether it will be modified by the use of expanding nozzles† or by other device, it is impossible to say at present. The turbine has, however, already reached such a high standard of efficiency compared with that obtainable within the temperature limits that unless these limits ‡ are themselves largely varied it would seem to resolve itself almost solely into a question of first cost. Turbines of any type obviously possess certain inherent advantages over reciprocating engines—they are cheap, simple, take up little room, and have no vibration. If therefore they can be made to run with reasonable economy in steam consumption and repairs they fulfil the essential requirements for power supply much more effectively than can the best reciprocating engine, whether high or low speed.

"Reliability of Supply" is met by their simplicity of construction. "Economy of Production" is met (*a*) by their low first cost (which is further helped by the small space occupied, a cheap foundation, and absence of vibration) and (*b*) by their economy in operation and saving in repairs, oil, and labour.

Actual experience of Steam Turbines.

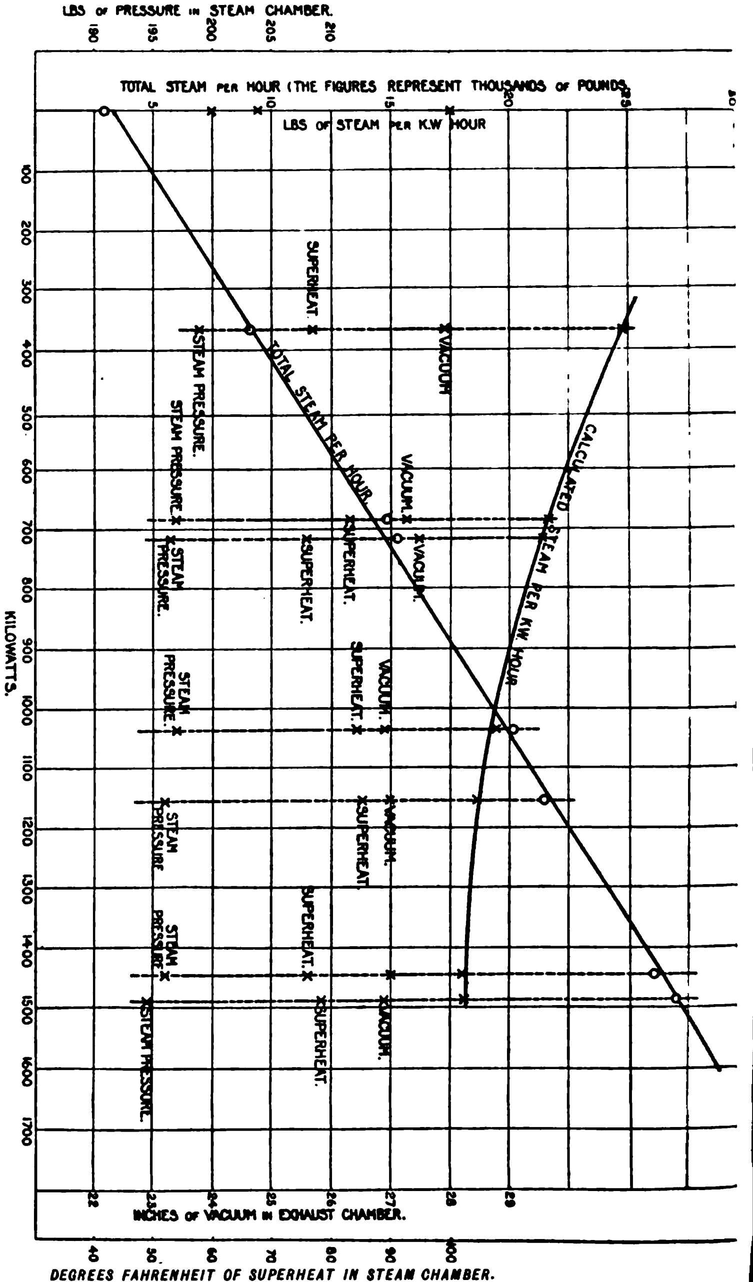
To any one with experience of large turbines there can be little or no question about any of these points, but as a great deal of information as to actual experience has not yet been published we may briefly refer to results obtained at Wallsend. We attach curves showing the steam consumption § of a 1,500 to 2,000 k.w. Turbine which was installed at the end of 1901. (Fig. 2.) The tests given were made after the Tur-

* See paper by Professor Rateau before the *Engineering Conference of the Institution of Civil Engineers*, June, 1903. ("*Engineering*," vol. lxxvi., p. 32.)

† With the exception of those of the Parsons type all turbines have some form of expanding stationary nozzle.

‡ The principal sources of loss in a turbine are leakage, eddy or fluid friction, and incomplete expansion. It is safe to assume that in no turbine will this be reduced to below 15 per cent. We may therefore assume that the best attainable result is that the turbine should return as useful work 85 per cent. of the total energy contained in steam between specified boiler and condenser temperatures. Assuming the efficiency of the dynamo, including the losses in bearings, excitation slip rings, oil pumps, etc., to be 90 per cent., then one kilowatt hour in the switchboard will, with steam at 200 lbs. pressure superheated 200° Fahr., and with a condenser temperature of 100° Fahr., require a consumption of 11·85 lbs. of steam—(from Rankine's formula). Turbines have already been constructed consuming 14·5 lbs. of steam per kilowatt hour at full load with a steam pressure of 190 lbs. superheated 200° F. and with 27·9 inches of vacuum in the condenser, so that future developments must be looked for rather in higher efficiency at low load and in the adoption of higher pressure or greater superheat.

§ The data are taken from the Log Sheets of the Newcastle-upon-Tyne Electric Supply Company who have operated two 2,000 k.w. Turbo-Alternators at their Neptune Bank Power Station, and are now installing a further 10,000 k.w. of Turbines at their new Carville Station. It is thought that the facts stated justify conclusively the installation of the trial turbines three years ago and the orders for new turbines which the Company have since placed.



STEAM CONSUMPTION TEST—PARSON'S TURBO ALTERNATOR. 1,500 K.W.

FIG. 2.

bine had run about 900 hours. After running 6,000 hours practically the same tests were repeated, and within the limits of observation the same results were obtained. The following table shows the hours of running, oil consumption, etc. :—

LOG OF NO. 10 TURBINE INSTALLED AT THE NEPTUNE BANK POWER STATION OF NEWCASTLE-UPON-TYNE ELECTRIC SUPPLY COMPANY.

Period.	Hours Running.	Hours out of Commission.	Remarks.
December, 1901, to August, 1902	2,090	—	Thrust adjusted
August, 1902, to September, 1902	471	4	Do. do.
September, 1902, to October, 1902	516	2	Thrust examined
October, 1902, to November, 1902	502	12	Governor overhauled
November, 1902, to August, 1903	1,788	18	Relay valve examined, thrust examined, new oil disc fitted
August, 1903, to December, 1903	1,596	4	Thrust examined
December, 1903	549	12	Repairs to governor throttle valve chest
	7,512	52	

Total hours run : 7,512. Out of commission for inspection and repairs to turbine : 52 hours. Oil used : 150 gallons at 3s. 6d. per gallon.

It will be noticed that the 2,000 k.w. turbine ran 7,500 hours without ever having been opened up, and only on two occasions have the bearings needed any re-setting in order to keep the clearance correct, although they were three times examined and the clearance tested. In fact the only faults of any kind which it has been necessary to repair have been the re-lining of one of the govenor throttle valve chests and the renewal of an oil disc. **Reliability of the Steam Turbine.**

Steam turbines seem in every respect to be specially suitable for Power Scheme purposes, and although they have taken many years to develop, it is probable that had there been a demand ten years ago for 2,000 k.w. generating sets turbo alternators would have been the only large size generating units in extensive use at the present day. Their earlier commercial success was prevented by the fact that there was only a demand for small sizes (300 k.w. and under), at which sizes any superiority which the turbine even at the present time possesses over reciprocating engines is due to saving of labour and oil rather than **Benefit of Steam Turbines to Power Schemes.**

to lower cost or reduced steam consumption. In large units the adoption of turbines materially reduces the capital cost of a Power Station. This reduction amounts to from 15 per cent. to 20 per cent. over the whole station even on present market prices, and it will be much greater when the manufacture of turbines has become as completely standardised as that of reciprocating engines: if the reduction be calculated on the engine and dynamo alone the percentage is naturally very much greater. The mere fact that this saving is not available in small sizes greatly assists a Power Company in its competition with private plants, as a private user utilising, as he must, relatively small units does not reap anything like the same advantage as a Power Company from the adoption of turbines either in first cost or in steam consumption. We are here discussing a station for Power Supply which involves alternating units, as large continuous current turbo-generators, due to the troubles of commutation at high speed have still a somewhat limited field.*

Gas engines.

The high thermal efficiency of gas engines has long rendered their use attractive to Power Station engineers, more especially in the south of England where coal is expensive, but although we may eventually look forward to the time when a gas motor fulfilling the requirements of a Power Station will be obtainable, it can hardly be denied that, for this purpose, the gas engine has not at present attained the same perfection as the steam turbine.†

Superiority of steam turbine over gas engine.

It is hardly open to question that steam turbines with a given amount of spare plant give greater security of supply than gas engines. It is also evident that the use of steam turbines simplifies the remainder of the power station and generally the system as a whole. Even if we say nothing about the difficulties attending the use of rotary converters of 40 or 50 cycles fed through long lengths of cable with gas engine driven plant, we doubt whether a balance sheet can be

* In cases where it is necessary or desirable to generate continuous current, Turbo Alternators plus Rotary Converters, even when the latter have to be installed in the same building, are frequently justifiable. If it be a question of a 500 volt network for traction or lighting and the radius to be dealt with does not justify one or two substations, rotary converters would be installed in the Power House and the generators would be of the revolving field type and wound for 330 volts so as to avoid step down transformers. Switchgear between generator and rotary would be dispensed with and each rotary and turbo set would be treated as one unit. The result would be :—CAPITAL COST.—Rotary plus Alternator as against low-tension direct-current Generator, an increase in first cost of perhaps £1 per k.w. which should be more than saved by the reduced cost of turbines compared with reciprocating engines. The rotary would not, of course, cost as much as the continuous current dynamo for the same output. ANNUAL COST.—A loss of say 5 per cent. in the rotary converter, as against the saving in steam, oil, and repairs, by the use of turbines.

† Apart altogether from the importance of utilising more efficiently the heat energy in coal there are large possibilities in utilising gas which is a waste product, or which is obtainable in conjunction with some manufacturing process. These possibilities make it particularly desirable to utilise gas direct in the prime mover without the agency of steam. This paper, however, refers essentially to the design of power stations where coal is the fuel, either in a boiler or in a gas retort. The conclusions drawn under this section must in no sense be taken as implying that in the opinion of the Authors gas engines are impracticable for power stations where waste gas from blast furnaces or other source is available. (See footnote opposite.)

drawn so as to come out favourably to the gas engine at the present moment.* The saving of coal varies of course in different localities, but even allowing for slight differences in favour of the gas engine compared with the steam turbine in this direction we would at present for all ordinary Power Station purposes in this country decide in favour of the steam turbine. We would draw our balance sheet as follows :—

Gas Engines.	*Turbines.*
Low Coal Bill.	
High Oil Costs.	Low Oil Costs.
High Labour Costs.	Low Labour Costs.
High Repair Costs.	Low Repair Costs.
and (most important of all)	and (most important of all)
High Capital Cost.	Low Capital Costs.

Low Capital Costs are even more important in this connection than in others, as depreciation charges are necessarily higher in gas engines than in turbines. Of course such improvements in gas engines may be made as will result in their superseding steam turbines, but if the advocates of gas engines are correct in stating that the present type of gas engine is being rapidly improved upon, it is the more advisable to instal at first a cheap plant in order to diminish the cost of superseding it when gas engines approach finality in development.

(II) GENERAL ARRANGEMENT.

As we are dealing more particularly with a station for Power Supply we must necessarily assume that land is reasonably cheap and that the site is of ample area in order to allow for future extensions. It is also desirable in order to permit the transmission cables to radiate in all directions that the site should be located well within the area to be served and not at its extreme boundary—though this latter consideration may be outweighed by the necessity of choosing the site so as to secure as cheaply as possible the raw material necessary, whether coal, waste gases, water, or stores. Location of Power Station.

The buildings necessary for a large Power Station and its operation are :— General lay-out of buildings.

(*a*) Main buildings containing the generating machinery.
(*b*) Switch house.
(*c*) Offices.
(*d*) Stores and repair shops.

The above buildings are frequently grouped into one block, and although this may result in some saving it would seem a mistake if we follow out the principle of sub-division. In the case of a steam station

* It is at present almost essential to use 40 or 50 cycles for power supply in order to deal with alternate-current lighting. If gas engines were used it would probably pay to utilise asynchronous alternators on the gas engines and to have one turbine always running on the circuit to keep the turning moment steady, and generally to control the system. It is the intention to do this in the Blaydon Power Station which the Authors are at present erecting.

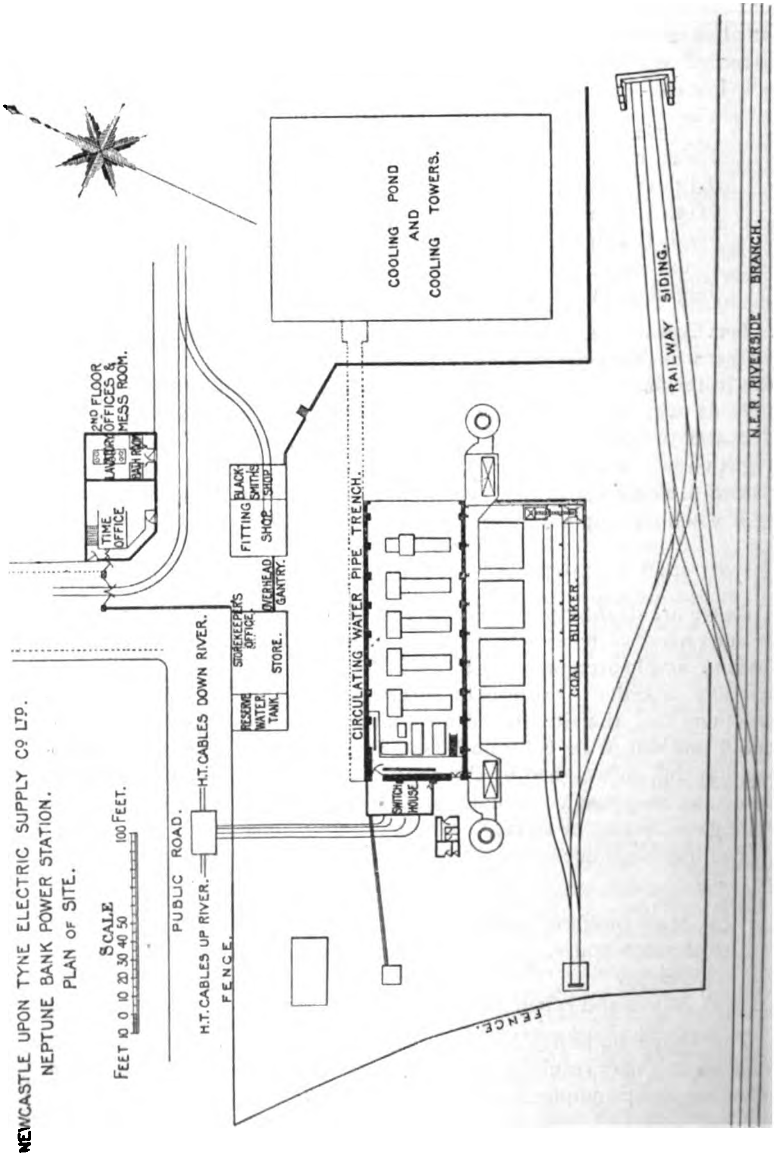
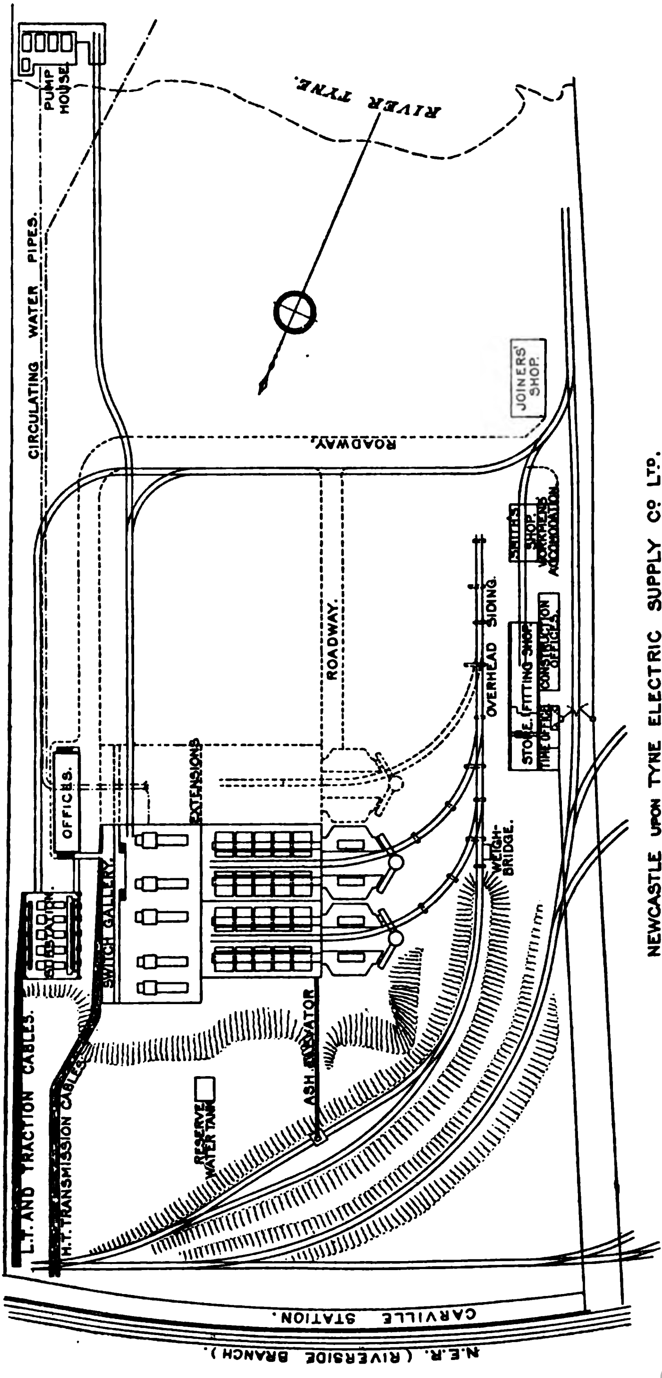

NEWCASTLE UPON TYNE ELECTRIC SUPPLY Cº LTD.
NEPTUNE BANK POWER STATION.
PLAN OF SITE.
SCALE
FEET 10 0 10 20 30 40 50 100 FEET.
PUBLIC ROAD.
H.T. CABLES UP RIVER.
H.T. CABLES DOWN RIVER.
FENCE.
FENCE.
TIME OFFICE
LAVATORY
BATH ROOM
2ND FLOOR OFFICES & MESS ROOM.
FITTING SHOP
BLACK SMITHS SHOP
OVERHEAD GANTRY.
STOREKEEPER'S OFFICE.
STORE.
RESERVE WATER TANK.
SWITCH HOUSE
CIRCULATING WATER PIPE TRENCH.
COOLING POND AND COOLING TOWERS.
COAL BUNKER.
RAILWAY SIDING.
N.E.R. RIVERSIDE BRANCH.

FIG. 3.



NEWCASTLE UPON TYNE ELECTRIC SUPPLY Co. LTD.
CARVILLE POWER STATION.
PLAN OF SITE.

SCALE.

FEET 10 0 20 40 60 80 100 200 FEET.

FIG. 4.

it is necessary, in order to avoid undue losses in steam pipes, to put the boiler house adjacent to the engine house.* The offices, stores and repair shops however should, in the opinion of the Authors, always be placed away from the main Power Station buildings. The advantage of doing this is that they need not be built so substantially, and all fire risks are avoided. Their relative position, however, both to the first instalment of the Power Station and to extensions, requires careful consideration. In deciding upon their location the following points should more especially be borne in mind :—

(1) Ease of extension of the auxiliary buildings themselves.
(2) Ease of transport of apparatus from the stores to the repair shop and from both to the main buildings.
(3) Delivery of goods to stores.
(4) Position relative to the works main entrance.
(5) Any outside purpose (*i.e.*, in addition to dealing with the Power Station) which the auxiliary buildings may be called upon to serve.

In commencing the construction of a Power Station, the auxiliary buildings, repair shops, stores, and all sidings, should be put down before the main buildings are started. This will enable considerable economy to be effected in the cost of constructing the main buildings. Figs. 3 and 4 show the general arrangement of auxiliary buildings at Neptune Bank and Carville.†

Main buildings, the Complete Unit System

With regard to the general lay-out of the main buildings, the modern station is tending towards what may be called the Complete Unit System.‡ For a large Power Station this tendency might with advantage be carried further than is the general practice at present, so that the only junction between the various units will be :—

(1) At the Railway siding or other source of coal supply.
(2) At the River or other source of circulating water supply.
(3) At the main busbars.

* Some engineers prefer to keep the switchgear in an entirely separate building, and there is much to be said in favour of this course, especially if the number of feeders is greatly in excess of the number of generators. A modification of the idea would be to build a separate feeder house. A decision on this point must to a great extent depend upon local conditions, the extent of the system, and the importance which the Power Station under consideration bears to the system as a whole.

† It will be observed in the case of Carville (*a*) that the offices, stores, and fitting shop are all separated from the main buildings, as is also the North Eastern Railway substation. (*b*) Easy communication has been provided between the offices, the main switch gallery, and the N.E.R. substation by means of an overhead enclosed gangway. (*c*) Siding communication is provided between the stores and repair shops and the main buildings. (*d*) An overhead hand traveller connects the stores and repair shops. (*e*) Both a railway siding and a road run into the stores. (*f*) Stores and construction offices are combined with time office and main entrance to works. It may be mentioned that in this particular case these buildings also act as Construction Offices and Repair Shops for the whole of the Newcastle Company's system.

‡ By a complete unit is not necessarily meant one generating set—a unit may consist of two or more generating sets with boilers and auxiliaries.

In fact a large Power Station might with advantage be so designed that the boiler house plant, the steam piping system, the generating system, and the switchboard, may all be entirely sub-divided into different units. The adoption of very large generating units has increased this tendency in recent Power Stations, which are now, in many cases, designed more after the lines of what might be termed marine practice—that is to say, each large generating set is provided with its own boilers and auxiliaries, and it is therefore under normal conditions entirely separate from the other units.

Main building should consist of a steel-framed structure.

So far as the nature of the building itself is concerned this is governed solely by the necessity for keeping down Capital expenditure, and it is practically speaking in no way affected by questions relating to reliability of supply and low running cost. On this account the structure may be treated merely as a shell to contain effectively, but as cheaply as possible, the generating plant. A steel-framed structure is in every way the most satisfactory, the filling in between the various columns being merely of the nature of a weatherproof screen wall, depending for its stability on the steel framing. This screen can be of brick, concrete, or corrugated iron—the last has the advantage that it can be more easily altered.* The complete buildings will consist of three components :—

(1) The Boiler-house (or Gas Generator House) to which the coal is delivered.
(2) The Engine-room containing engines, generators, and auxiliaries.
(3) The Switch Galleries or separate Switch-house, from which the generation of energy is controlled and from which the cables emerge.

Relative position of boilers, engines and switchgear.

In order that each of these sub-divisions may permit of general systematic extension to meet as far as possible all future engineering developments, the switch galleries must run parallel to the longitudinal axis of the engine-room,† the boiler-house being placed along the side of the engine-house opposite to the switch gallery. In the boiler-house provision will be required for coal and ash-handling plant and for the storage of a considerable quantity of coal, so that even if a sudden strike should cut off the usual supply the station staff may have a sufficient coal reserve to allow of them negotiating for a supply from other sources. In order to secure the shortest possible steam pipe it is imperative that the boilers should be located directly opposite the engines they normally supply. For similar reasons these engines should be closely adjacent to their condensers, which, in turn, should be

* This feature, namely, that it should be possible with the minimum of expense to take advantage of radical improvements, is also worthy of consideration in connection with the site chosen.

† This is advisable whether they are in a separate building or not. One serious objection to the placing of the switchboard at the end of the building is the concentration of leads running to the board, the practical impossibility of avoiding crossings of cables, and the fact that the width of the building limits the possible extension of the switchgear.

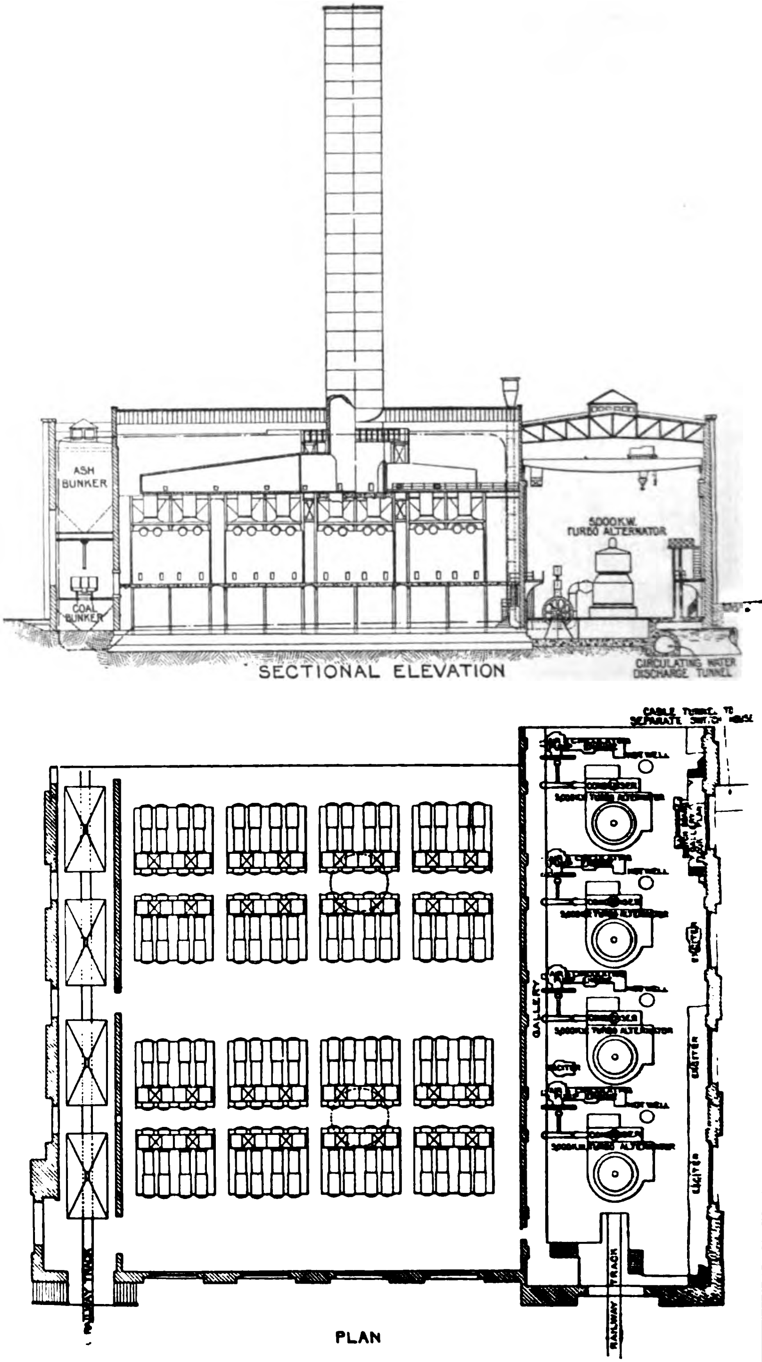
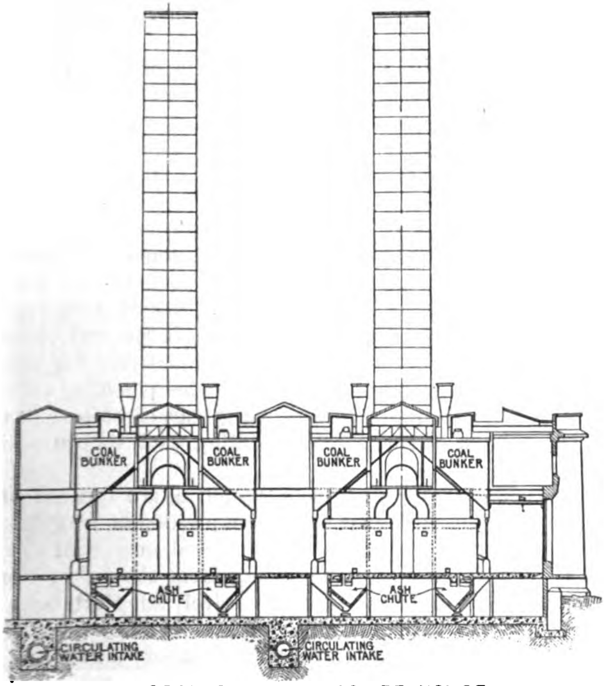

ASH BUNKER
COAL BUNKER
5000 K.W. TURBO ALTERNATOR
CIRCULATING WATER DISCHARGE TUNNEL
SECTIONAL ELEVATION
GALLERY
RAILWAY TRACK
PLAN

FIG. 5 (*a*).



SECTION THROUGH BOILER HOUSE

GENERAL ARRANGEMENT SHEWING FOUR COMPLETE UNITS
FISK STREET POWER STATION
COMMONWEALTH ELECTRIC COMPANY, CHICAGO

SCALE OF FEET
10 0 10 20 30 40 50 60 70 80 90

FIG. 5 (*b*).

almost directly above the circulating water inlet and outlet mains. On the electrical side similar reasons hold, the generator panels should be as close as possible to their respective generators. In short, the whole lay-out should be designed with the idea of avoiding crossings and of obtaining the shortest and most direct run of all connections, whether piping or cables.

General lay-out of Large Power Station.

For a comparatively large Power Station, of say an initial capacity of 10,000 k.w. capable of extension to three or four times this size, and especially for one utilising steam turbines, the general arrangement shown by Figs. 6 and 7 is convenient, as it fulfils the several requirements we have laid down, namely (1) simplicity of design; (2) sub-division of plant; (3) saving of labour; (4) ease of extension.

A turbine occupies so little floor space in comparison with its output that it is impossible to adopt what had almost become a standard arrangement, *i.e.*, having one or two lines of boilers parallel with the engine-room, as by so doing sufficient boiler-house capacity could not be obtained without wasting an excessive amount of floor space in the engine-room through spacing the turbines very far apart. In fact with turbines there are only two alternatives possible, either to have a two storey boiler-house or to arrange groups of boilers at right angles to the axis of the engine-room, providing each turbine with its own group of boilers.*

Other arrangements of main buildings.

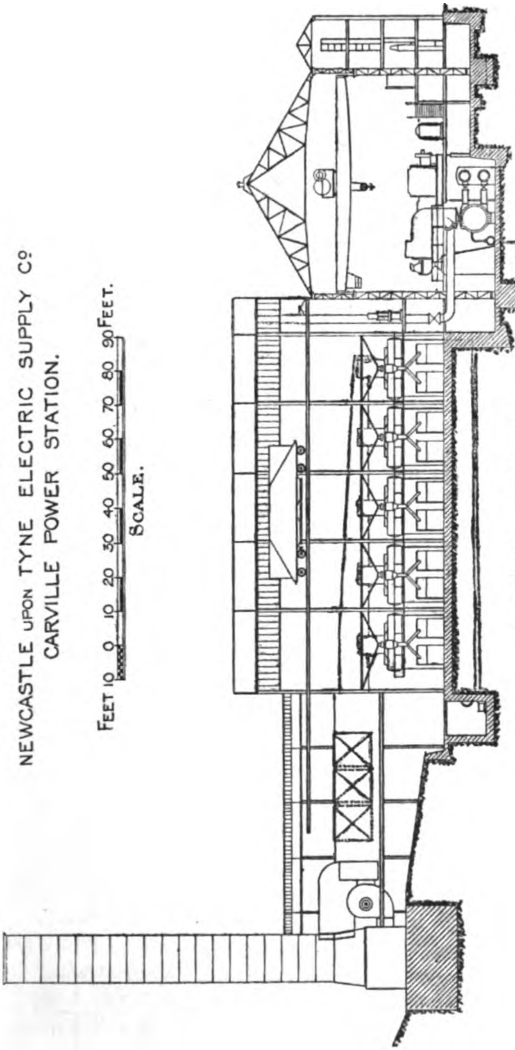
The designs shown in Figs. 7, 8, and 9, are typical of the three possible arrangements so far as relative position of engines and boilers are concerned. Fig. 8 may be considered most suitable for Power Stations up to 5,000 k.w. The arrangement shown in Fig. 9 with the double row of boilers has been extensively adopted both in this and other countries. It has, however, many objections—it is difficult to allow for unlimited extension, and the steam and feed piping are considerably longer than in other arrangements. For all Power Stations of over 5,000 k.w. capacity, especially stations for Power Supply (which must be designed for large extensions) the Authors consider the arrangement shown by Figs. 5, 6 and 7 the best and most flexible. It may be specially noted how this design facilitates an alteration in the size of units without upsetting the general arrangement of the station, as the extension boiler-houses may be longer.

Arrangement of Auxiliary apparatus.

The arrangement of the auxiliary plant (including in this term all piping and cable connections) is a most important factor in the design of the engine-room. A design which probably originated on the Continent, and which is carried out there extensively, has also been largely adopted in this country, *i.e.*, the provision of a basement to contain all pipes and auxiliary machinery. Experience has shown this to be an extravagant method, affecting adversely both capital and running costs. It is, in short, directly antagonistic to the requirements which we have laid down as essential to an efficient design. It is also

* A similar arrangement has been adopted by Messrs. Sargent and Lundy for the new stations at Boston and Chicago (see Fig. 5), where Curtis turbines are being installed. The Authors have independently adopted it at Carville, where Parsons turbines are in use. (See Figs. 6 and 7.)

expensive in running wages, as unless the plant be allowed to run with practically no attention, more men are required, and it is expensive in repairs on account of the difficulty of providing lifting tackle and the necessity of working entirely with localised artificial light. Against



SECTIONAL ELEVATION.

FIG. 6.

these objections the only advantage is a clean engine-room floor. Various arrangements have been adopted by engineers to avoid the inherent defect of installing the auxiliary apparatus in the basement. The provision of wells or pits instead of a basement in the main engine-room has been frequently adopted, and though this arrange-

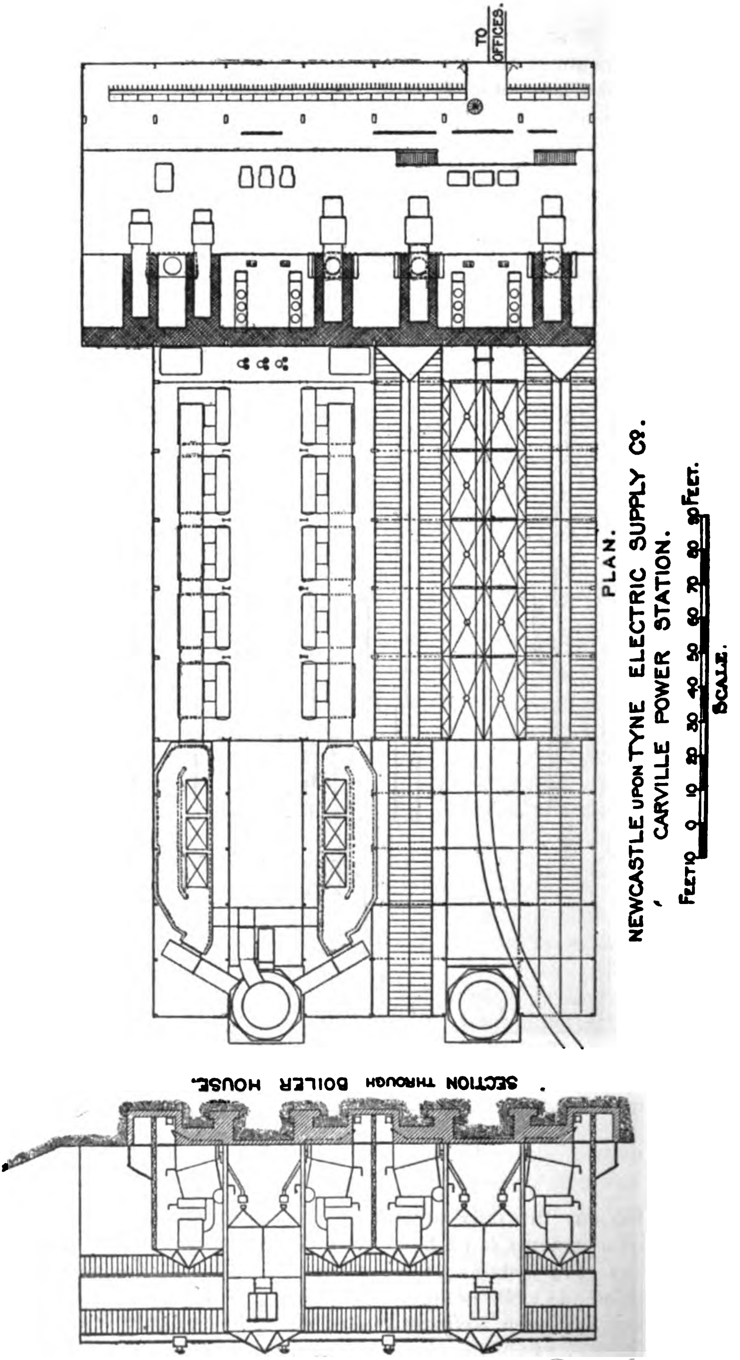

TO OFFICES.
PLAN.
NEWCASTLE UPON TYNE ELECTRIC SUPPLY Co.
CARVILLE POWER STATION.
FEET 10 0 10 20 30 40 50 60 70 80 90 FEET.
SCALE.
SECTION THROUGH BOILER HOUSE.

FIG. 7.

ment hardly gets over the difficulty with regard to piping, it certainly reduces the supervision and attention required.

The turbine, on account of the small floor space which it occupies, has simplified matters immensely, as with it all apparatus can easily be put on the one floor, or (as is desirable on account of increased efficiency), the condenser may be placed directly *below* the turbine;* in the latter case the turbine, as it requires little or no attention, can be left to run by itself at a higher level with merely a gallery round it. The auxiliary apparatus, requiring as it does much more attention, can then be put on what may be regarded as the main floor. Both arrangements allow of all apparatus being conveniently handled by the main crane—though neither provides that perfect-looking engine-room which is a feature of many Continental stations.

(III.) SPARE PLANT AND THE RATING OF PLANT.

Spare Plant and Over-load Capacity.

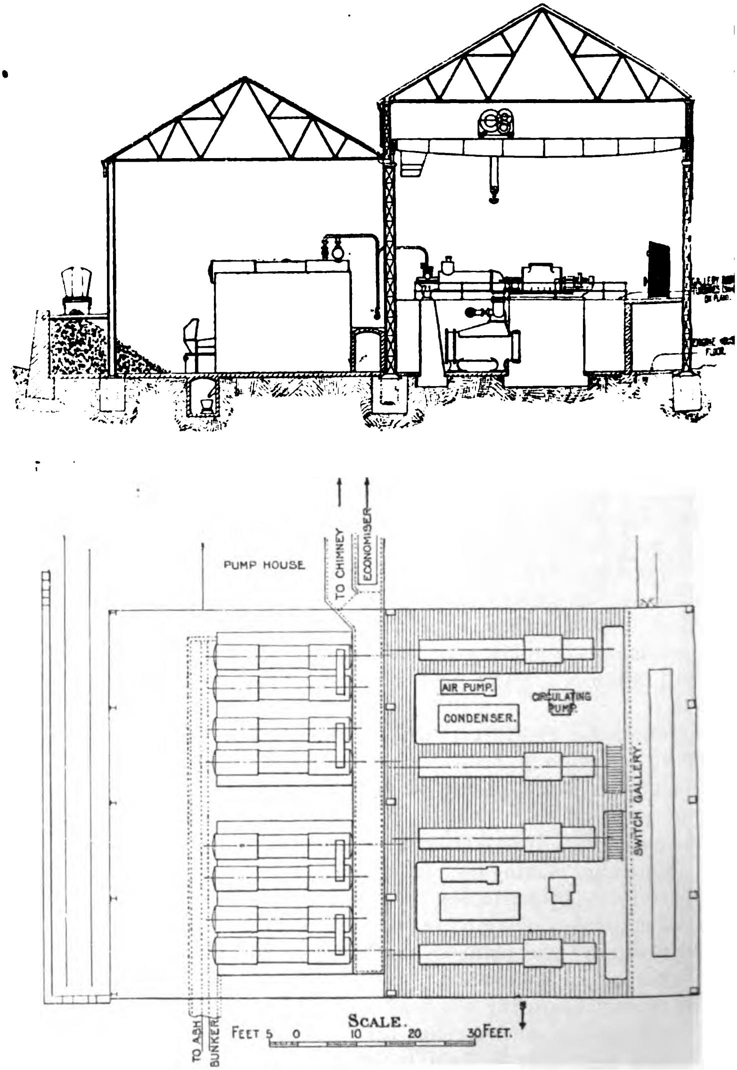
The whole question of spare plant and its proportion to the output of the station is an important one in design—as also is that of securing the correct relative capacity of the various pieces of apparatus making up a complete unit: the boiler, the engine, the generator, and the switch-gear. On the one hand, if the various components in the station which make up a complete unit have different degrees of reliability, or if some require more overhauling and inspection than others, then obviously different margins of spare plant are required. Again, while every piece of apparatus may be said to have one point at which it works at maximum economy, overload capacity is generally obtainable at small expense, though possibly by some sacrifice of running economy.

We suggest that a very great saving can be made in the total cost of production (through a reduction of capital charges)† if proper attention be paid to these points, as follows:—

(1) By correctly apportioning the spare plant for each piece of apparatus making up a complete unit.
(2) By correctly apportioning the overload capacity of each piece of apparatus making up a complete unit.
(3) By designing the plant so that the economical rating of each component is identical.
(4) By relying upon the overload capacity not only for dealing with sudden emergencies (say a shut-down of one of the units that may happen to be running at the time), but also depending upon it for the ordinary peak load of the station, or when other plant is being overhauled.

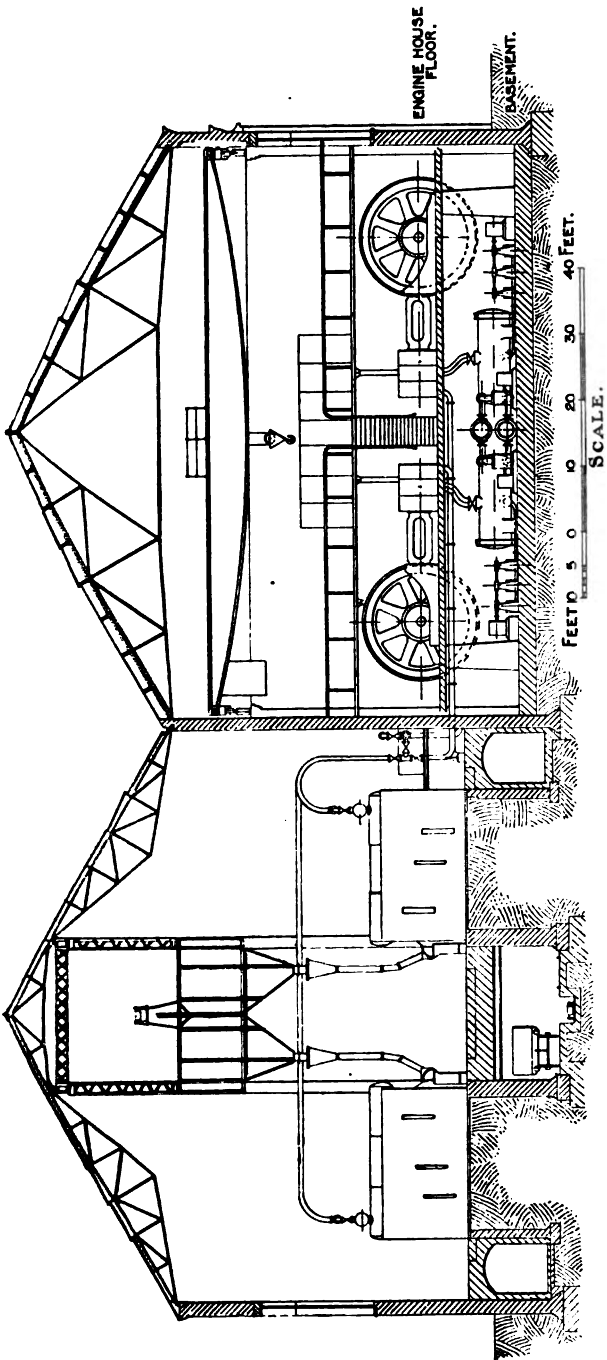
* The General Electric Company of America are developing their Curtis turbine with a condenser in the base of the turbine itself, which at once secures this advantage. In the case of small units it is an advantage to provide a condenser for each pair of sets, as in this way at light loads the advantage of a high vacuum is obtained.

† For importance of Low Capital Charges see page 700 and Fig. 1.



DESIGN OF POWER STATION.
SINGLE ROW OF BOILERS.

FIG. 8.



GENERATING STATION WITH DOUBLE ROW OF BOILERS.

FIG. 9.

In a gas-engine, as the economical rating coincides with the maximum rating, both peak and breakdowns can only be met by installing additional plant. In the case of a steam station, if the load under normal (not peak) conditions is equal to the economical rating of one machine only, then it is clear that while it might be possible to take care of the peak with the overload capacity of that machine, an additional unit is essential to allow for periodical overhaul and to guard against failure through the breakdown of a unit-section.

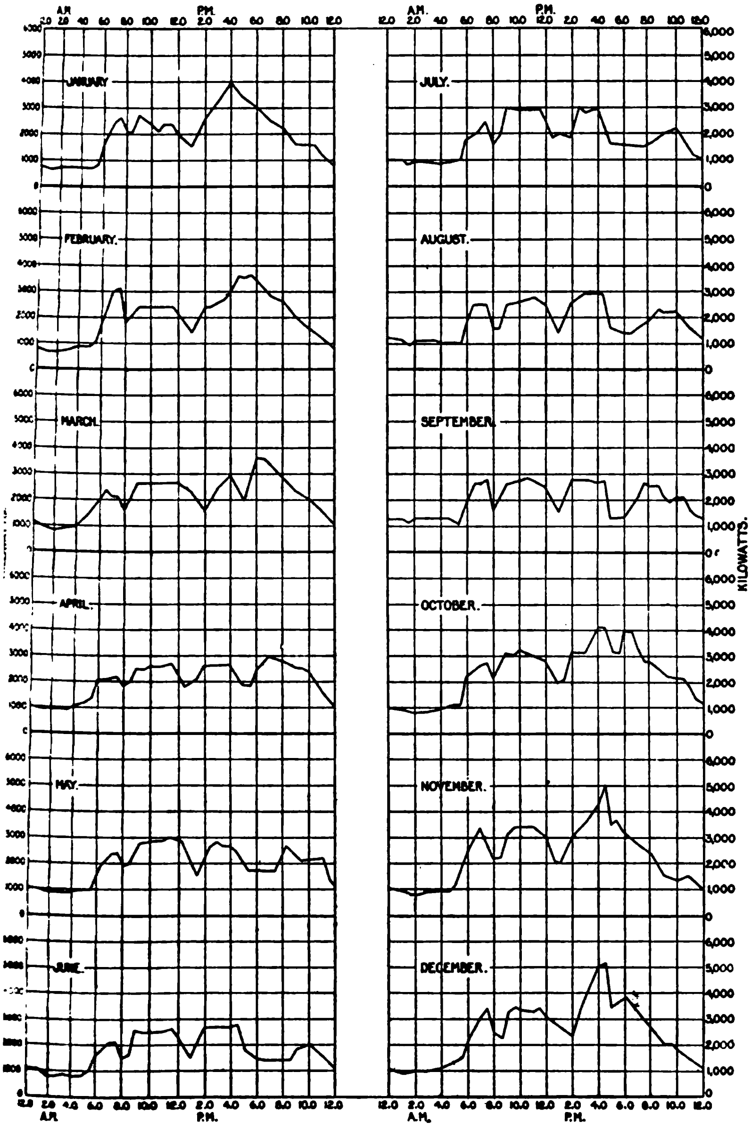
Effect of peak at Neptune Bank Power Station.

The three factors to be met by the installation of machines having an overload capacity and by the provision of spare machines are: (1) the peak, (2) periodical overhaul, (3) breakdowns. Whether any or all of these factors are best met by additional plant or by overload capacity depends on the number of units installed and on the relation between the peak and the overload capacity procurable; but in any case it seems to us important to take the overload capacity into consideration in designing a station, and to consider it a feature in design —not merely a casual advantage which may happen to come in useful. We attach twelve typical load curves, one for each month of the year 1903 for the Neptune Bank Power Station. (Fig. 10.) As a matter of fact, if we take the year in question and consider the normal load as 100, the peak load is 100 per cent. higher, or 200. The total number of units sent out of the station while the load was at or below normal (100) was more that 80 per cent. of the total number of units sent out during the year. In other words, if this 100 per cent. peak is represented by 100 per cent. extra plant, the 100 per cent. of extra plant only turned out a proportion of the balance of 20 per cent. of the total units.

Overload Capacity in the components of each Unit.

While, therefore, it is important that the plant should operate economically at normal rating, it is of equal importance that it should have a uniformly high overload capacity. Little regard need be paid to the running costs at the peak, as the resulting fractional increased coal consumption is far more than balanced by the saving in capital charges.* The steam turbine lends itself admirably to dealing with large overloads, as by means of a bye-pass admitting high-pressure steam to the low-pressure section of the turbine the capacity of the turbine can be increased 50 per cent., though this is, of course, accompanied by a certain drop in economy. Standard designs of alternators can be built without excessive cost to stand an overload of 50 per cent. for two hours. If, therefore, the boiler plant has a similar range of elasticity, the peak can be met by simply forcing all plant beyond its economical production point, and by doing the same in the engine-room if any of the units are out of commission for overhaul. There is no great difficulty in securing that the boilers shall have the necessary elasticity even under natural draught, but under mechanical draught the solution

* It does not follow that even the fuel costs must necessarily be increased by forcing the plant at the peak. In the case of a very short peak, such as is formed by the load of works which shut down at five o'clock overlapping the lighting load, the all day economy of the boiler-house may be actually improved, due to the fewer boilers kept under steam. On account of possible low steam pressure, however, this is only safe with proper induced draught, giving ample margin for forcing.



NEPTUNE BANK POWER STATION.

LOAD CURVES ON TYPICAL DAY FOR EACH MONTH IN 1903.

FIG. 10.

is easy. In fact the adoption of artificial draught improves the control of the boiler-house plant so enormously under ordinary conditions that it is, in our opinion, desirable to instal it apart altogether from the question of emergency output.

Basis of rating Power Stations.

Apart from actual personal experience, it is only by comparing one station with another that an engineer can hope to improve his design, so far as low capital cost is concerned. It is, therefore, important that the basis of comparison should be fair and uniform, but it is not a particularly simple problem to define what this uniform basis should be. It is evident, for instance, that for all practical purposes a station containing, say, four steam turbines, each of a normal economical rating of 2,500 k.w., is of larger capacity than a station containing two turbines each of a normal economical rating of 5,000 k.w., while these steam stations are respectively of larger capacity than a gas-engine station containing four units of 2,500 k.w. normal economical rating, or two units of 5,000 k.w. normal economical rating. As can be seen at a glance from the following table, there are eight different ways in which a station may be rated :—

	Continuously.	For a short period.
Maximum possible load	(1)	(5)
Maximum economical load ...	(2)	(6)
Maximum possible, less allowance for spare plant...	(3)	(7)
Maximum economical, less allowance for spare plant	(4)	(8)

(1) On the basis of the maximum *possible* load which the station is capable of dealing with continuously, making no allowance for spare plant.
(2) On the basis of the maximum *economical* load which the station is capable of dealing with continuously, making no allowance for spare plant.
(3) On the basis of the maximum possible load which the station is capable of dealing with continuously, *less an allowance for spare plant.*
(4) On the basis of the maximum economical load which the station is capable of dealing with continuously, *less an allowance for spare plant.*
(5) On the basis of the maximum *possible* load which the station is capable of dealing with for a short period, making no allowance for spare plant.
(6) On the basis of the maximum *economical* load which the station is capable of dealing with for a short period, making no allowance for spare plant.
(7) On the basis of the maximum possible load which the station is capable of dealing with for a short period, *less an allowance for spare plant.*
(8) On the basis of the maximum economical load which the station is capable of dealing with for a short period, *less an allowance for spare plant.*

Suggested common basis for rating Power Stations.

Of the above, No. 4 would seem, at first sight, to be the most reasonable, *i.e.*, rating the station on the basis of the maximum economical continuous output, making due allowance for spare plant. This would certainly be correct if we were dealing with load-factors of 100 per cent., as of course in such cases practically the only value of overload capacity is for dealing with a sudden emergency due to the failure of one of the running units. As, however, we are considering essentially a station for Power Supply where the load-factor over the year may be expected not to exceed 25 to 30 per cent., low cost of production will be facilitated by the engineer considering Capital Expenditure rather from the point of view of the most economical way

of dealing with the peak load, or in other words, if in estimating the capital cost he considers that the rating of the station is based on its maximum possible output for one or two hours—that is to say on the basis of No. 5.

The Authors consider that by proper attention to spares and overload capacity the cost per k.w. of maximum output of a Power Station can be reduced from 20 to 40 per cent., depending, of course, on the load-factor to be dealt with.

The selection of a suitable size for the generating units is a question which is intimately associated with that of spare plant and capital cost, more particularly where future extensions are taken into account. Size of Unit.

That the *number* of units should be kept as low as possible (especially with steam turbines) may be taken as axiomatic; and this, of course, points to units of large size. On the other hand a limit is set to this reduction in *number* by the following factors:—

(*a*) The amplitude of load variation throughout the twenty-four hours, or at different seasons of the year.
(*b*) The capital cost of spare plant.

In general, a solution which meets (*b*) will also be consistent with (*a*).

(IV.) AUXILIARY MACHINERY.

A careful analysis of the repair and labour accounts of any Power Station, especially one where steam turbines are installed, shows that a very large percentage of the items are accounted for by the auxiliary machinery and apparatus. When we also consider that they represent about 10 per cent. of the total power installed in the station, it is evident that in order to fulfil the essential conditions we have laid down it is worth while devoting considerable attention to the choice and arrangement of this apparatus. When a main unit is running the whole of the corresponding auxiliary plant is operating at practically full load, whatever be the load on the main unit. As a consequence the auxiliaries are responsible for about 15 per cent. of the total coal bill of the station —due regard therefore should be paid to their economy. On the other hand the factors governing the design of auxiliaries are the same as those controlling the choice of the main plant; that is to say, they must provide as effectively as possible, firstly for the reliability, and secondly for the economy of the *main* supply. It is necessary to bear the relative importance of reliability and economy in mind, when considering which system to adopt, and to face the sacrifice of running economy of the auxiliary plant to a material extent if by so doing additional reliability is secured. Auxiliary apparatus generally may be divided into:— Importance of Auxiliaries.

Different means of driving Auxiliaries.

(*a*) Steam-driven auxiliaries.
(*b*) Electrically-driven auxiliaries.

After making a careful balance-sheet of the respective merits of steam and electrically-driven auxiliaries it will be found that it is impossible to lay down any hard and fast rule which will apply to all cases or to all classes of auxiliary machinery, partly on account of the widely different

conditions under which the machinery has to operate, and partly on account of the effect which the general design of the station has on this question. For instance, the American practice of omitting economisers leads to the adoption of steam-driven auxiliaries exhausting into feed-water heaters, while as economisers are almost universally installed in English and Continental practice it follows that there is less gain to be derived from exhaust steam-feed heaters.* To adopt electrically-driven auxiliaries either involves that the capacity of the main generating units be increased by 10 per cent., or as an alternative that this amount of special generating plant be installed. In either case the cost of the additional generating plant must be debited against electrical auxiliaries, as steam-driven apparatus merely requires the provision of the additional boiler capacity.

The running account will be made up of the capital charges resulting from first cost, of the repairs and attendance charges, and of the actual cost of fuel. In considering these along with the question of reliability † it is convenient to arrange the auxiliaries in a steam station under the following heads :—

(1) Boiler-house drives, *i.e.*, Stokers, Coal and Ash Conveyers Economisers and Fans.
(2) Circulating and air-pumps.
(3) Feed-pumps.
(4) Exciters.

Electricity *v.* Steam for driving Auxiliaries.

Dealing with these *seriatim* :—

(1) It will almost invariably be found that even apart from the question of reliability it is best to adopt electrical driving for the machinery in the boiler-house. The units are small, and if steam-driven wasteful of steam and expensive in repairs and attendance.

(2) As to the circulating and air-pumps, we are of opinion that here also electrical driving is preferable, save only in the case of stations having slow-speed reciprocating main engines, where the air-pumps may with advantage be driven direct from the main sets. The circulating pumps have occasionally to be situated some distance from the station, in which case electrical operation is especially advantageous.

(3) The feed-pumps are a more difficult problem. They operate at variable speed, whereas all other auxiliary plant in the station operates at constant speed. In addition to this steam feed-pumps have for years been standardised—their first cost is low and their reliability high. They are needed even when the boiler fires are banked, and when no plant is running in the station; and though this last argument is admittedly not a weighty one, it would appear desirable to put down

* In this connection it may be noted that the installation of economisers offers more attractions with mechanical draught than with natural draught ; in the former case the temperature of the flue gases at the base of the chimney need not be considered, and as a consequence they may be deprived of more heat.

† This, in the case of all electrical auxiliaries, is more a question of reliability of the supply of electrical energy to the motors driving the auxiliary plant than of the plant itself.

steam-driven feed-pumps for, at any rate, the first instalment of plant. That this system of having steam-driven feed-pumps at the commencements and electrically-driven feed-pumps for extensions has much to commend it is evidenced by the fact that it has been adopted in many cases both in this country and abroad.

Methods of electrically driving the Auxiliaries.

From the above it would appear that at any rate the major portion of the auxiliary plant under the first three heads should be electrically driven,* and before proceeding to discuss the question of exciters, it may be as well to consider the best way of obtaining and applying electricity for operating the auxiliaries already discussed. There are four obvious methods of driving electrically the auxiliary machinery :—

(*a*) From the main busbars.
(*b*) From the main busbars with a reserve battery.
(*c*) From separate generating sets.
(*d*) From separate generating sets, with the addition of a connection to the main busbars to meet emergency conditions.

Of these (*a*) is the simplest method, the objection being that a total failure of supply stops not only the main units but the auxiliaries—thus extending the duration of the failure owing to the necessity of again starting up the auxiliaries before the main units can be got under way.

The second alternative (*b*) has the advantage that the auxiliaries can always be kept running even though the main plant be shut down. It is, however, more complicated than (*a*), particularly in an alternate-current station, as it involves the interposition of a motor generator between the busbars and the battery.

The most flexible system is (*c*), especially when the station is of sufficient capacity to justify the erection of auxiliary generating units of reasonable size. There still exists the possible danger due to failure, this can either be met by the instalment of a battery or by taking current in emergency from the main busbars on the lines of (*d*). This latter method offers many advantages, as it is preferable that the motors installed should be of the polyphase type.

If polyphase motors be adopted and if, as would appear desirable, steam feed-pumps are installed in the first instance, then as continuous current is required for excitation both the feed-pumps and exciters may be left out of consideration, and it is of less importance than it otherwise would be to guard against failure of the polyphase auxiliaries. It is therefore justifiable, with the ultimate adoption of (*d*) in view, to start the first instalment of a Power Station with polyphase auxiliaries operated through stationary transformers from the main busbars, without, for the time being, providing any alternative source of supply, the separate generating unit for operating auxiliary plant alone would not

* The balance of advantages would still further lie with electrically-driven auxiliaries if it were possible to obtain efficient rotary feed and air-pumps. There is no inherent difficulty in designing the former, and they have been installed in various places.

be installed until justified by the load. In other words, method (*a*) may be adopted in the first instance with the idea of ultimately arranging for (*d*).

The complete unit system as applied to Auxiliaries.

There is a further possible method—an extension of the complete unit system—which possesses many attractions, though, so far as we know, it has not been used anywhere. It consists in driving the whole of the auxiliaries from the particular main unit which they serve by connecting stationary transformers direct to the alternator terminals, these transformers being of sufficient capacity to operate air-pumps, centrifugal pumps, stoker, induced draught fan, and even, if desired, feed pumps—all in permanent connection through a switch with the main unit. In starting up the switches controlling air-pumps and centrifugal pumps may be left in and the field of the main generator excited. These auxiliaries would then start up with the main machine, just as if they were mechanically coupled or geared to it. Flexible connections would be provided so that motors, feed-pumps, or induced draught fans could be used as spares for other sets, but normally each main unit would deal with its own auxiliaries and would be independent of all others. The chief advantages offered are simplification and consequent saving in switchgear, and also, we think, increased reliability. It will be seen that the busbars are protected from any failure of the stationary transformer by the main machine switch. (See Fig. 11.)

Exciting Circuits.

(4) We come now to the question of excitation—one which has always attracted considerable attention. Numerous attempts have been made to run each exciter from the main shaft of its own alternator, but this method has not been generally adopted, chiefly due to the fact that in any variation of speed this variation, and the variation of the exciting current, have a cumulative effect on the busbar voltage, and this effect is heightened by the unstable nature of a small low-speed direct-current machine. The Authors are, however, of opinion that with high-speed engines, and more particularly with steam turbines, any difficulties there are may be readily overcome, and that the simple arrangement of coupling the exciter to the end of the alternator shaft may be safely adopted.

The modern practice of operating all switchgear electrically almost necessarily involves the use of a small battery. It is convenient to utilise this battery to excite the fields of the direct coupled exciters —it may also be used as a spare to meet the possible failure of one of the exciters. Such an arrangement carried out is shown in Fig. 12. Here two batteries are installed, from one or other of which the exciter field current is normally supplied, but should an exciter break down the battery may be used for exciting the alternator direct. Two batteries are installed so that there may be no variation of exciting voltage while one is being charged, and the batteries, in addition to supplying current for excitation and for operating the electrical switches, can feed the emergency lighting circuits throughout the station.

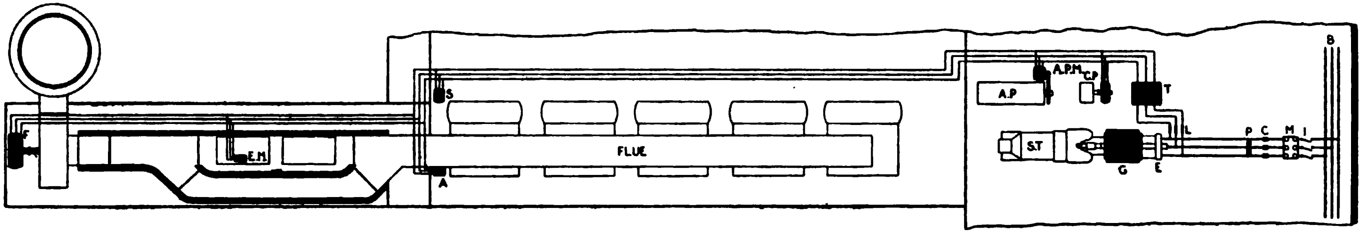
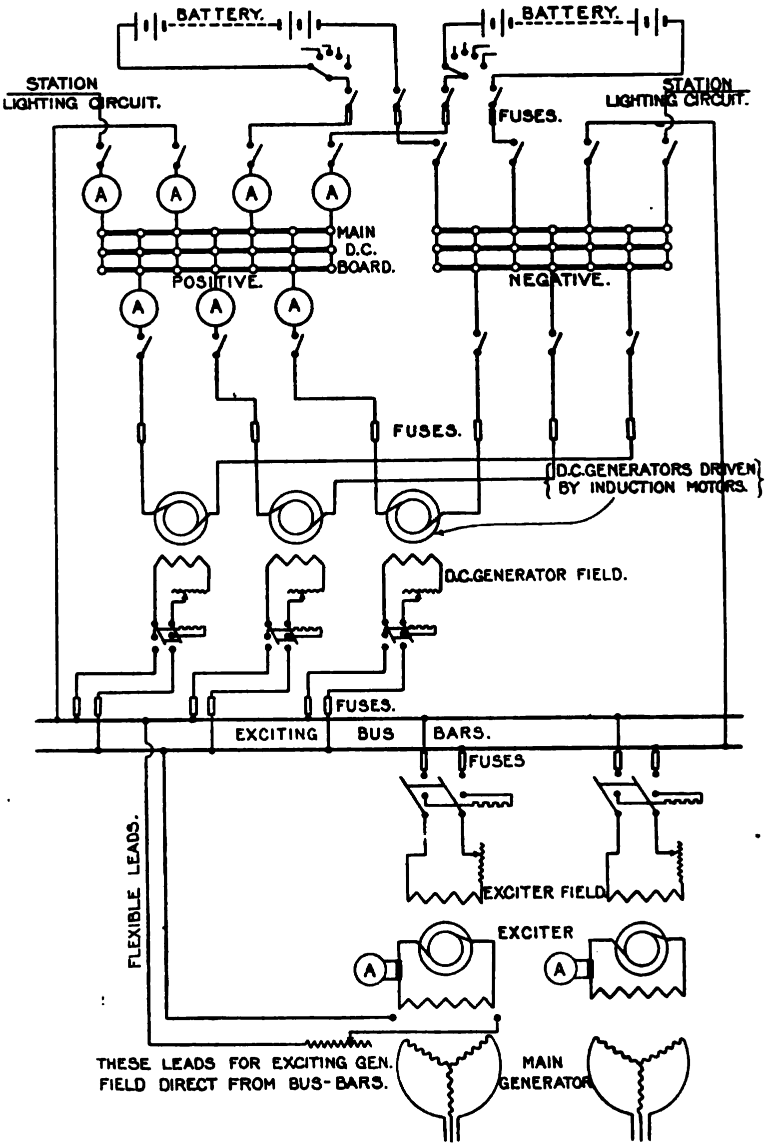


FIG. 11.—DIAGRAM SHOWING COMPLETE UNIT SYSTEM FOR OPERATING AUXILIARIES.

A = Ash-handiing Motor.
A P = Air Pump.
A P M = Air-pump Motor.
B = Bus Bar.
C = Current Transformers.
C P = Circulating Pump and Motor.
D = Disconnecting Link.
E = Exciter.
E M = Economiser Motor.
F = Fan Motor.
G = Main Generator.
I = Isolating Switches.
L = Link Fuses.
M = Main Oil-Switch.
P = Potential Transformer.
S = Stoker Motor.
S T = Steam Turbine.
T = Transformer.



EXCITING CIRCUIT DIAGRAM.
CARVILLE POWER STATION.

FIG. 12.

(5) SWITCHGEAR.

Importance of Reliability of Switchgear.

Every engineer who has had experience in the operation of a large station appreciates of what vital importance it is that the switchgear should be efficient and reliable under all conditions. We have already pointed out (page 712) that the main busbars are one of the three places in the station where a junction must be made between the various units which, from the boiler-house to the switchgear, may be kept completely independent of one another. Switchgear suitable for large Power Stations has only been recently developed, and on this account reliability of operation can only be secured by a relatively heavy capital outlay. As the manufacture of high tension switches and automatic protective devices becomes standardised and better understood we may look for a reduction in first cost. In the case of switchgear it is capital expenditure only which affects economy of production, the actual charges for maintenance should not be high, and as for cost of attendance this does not vary much for different types, though of course undue complication increases the running cost. On account of the absolute crippling of the Power Station which takes place if there be any serious failure of the switchgear, it is certainly justifiable to take every precaution to secure reliability even at the expense of capital expenditure. Under the section "Switchgear" we include not only the switchgear itself, but all electrical connections from the machine terminals to the main busbars, and from these to the outgoing feeders.

As in other sections of a Power Station, reliability of supply is best met by adopting a systematic and simple design and by properly subdividing all apparatus. Proper attention to the former will also tend considerably towards the reduction of capital cost, both in the first instance, and more particularly as the station grows—systematic design necessarily implying that due regard be paid to possible extensions.

Features of Modern Switchgear.

The simplicity of the Ferranti single-phase board probably first directed the attention of engineers to the necessity for subdividing High Tension switchgear from the machine to the busbars, at the busbars themselves, and from the busbars to the outgoing feeder. Recent tendency in switchboard design * seems at first sight a retrograde step in the way of complication. The extra complication, however, is due rather to the fact that the system is a three-phase one † than that complication has been introduced. In fact, a modern board is practically a large Ferranti board controlled from a distance.

Reference to the drawings of two switchboards which have recently been installed will facilitate discussion of the essential points.

* See *Transactions American Institution of Electrical Engineers*, vol. 18, "The Control of High Potential Systems of large Power," by E. W. Rice, junr. See also "Three-Phase Switchgear," by A. C. Eborall, *Engineering*, vol. lxxvi., p. 409.

† Even if single-phase motors are largely introduced for traction or other purposes, it seems probable that three-phase generation and distribution will still be resorted to, on account of—*(a)* cheaper machines, *(b)* cheaper and more easily insulated cables.

Figs. 13 and 14 show the arrangement of switchgear designed and adopted by the Authors at Carville where British Thomson-Houston switches are utilised, and Fig. 15 shows that for the five North-Eastern Railway substations where Westinghouse switches are used.

Where large powers have to be dealt with, that is to say where one switch may have to open 10,000 k.w. or more, the serious effect of the failure of a switch and the consequent necessity for completely subdivided apparatus will be readily realised. In both of the above designs this subdivision is provided for not only between the various pieces of apparatus and connections, but, as may be seen from the drawings, also between the different phases of the main switch itself—in fact, the only place where two phases come together is in the potential transformer chamber. The whole board in each case is made of concrete* from 3 inches to 6 inches thick. In designing the switch-house building it is necessary that all material should be fireproof, and this applies not only to the building itself, but as far as possible to all apparatus installed therein. The exigencies of space forbid a discussion of the details of each individual piece of apparatus, and as this paper deals more particularly with the assembling of apparatus rather than its design we can only consider the requirements to be met, merely referring to apparatus without attempting to describe it.

Main switches.

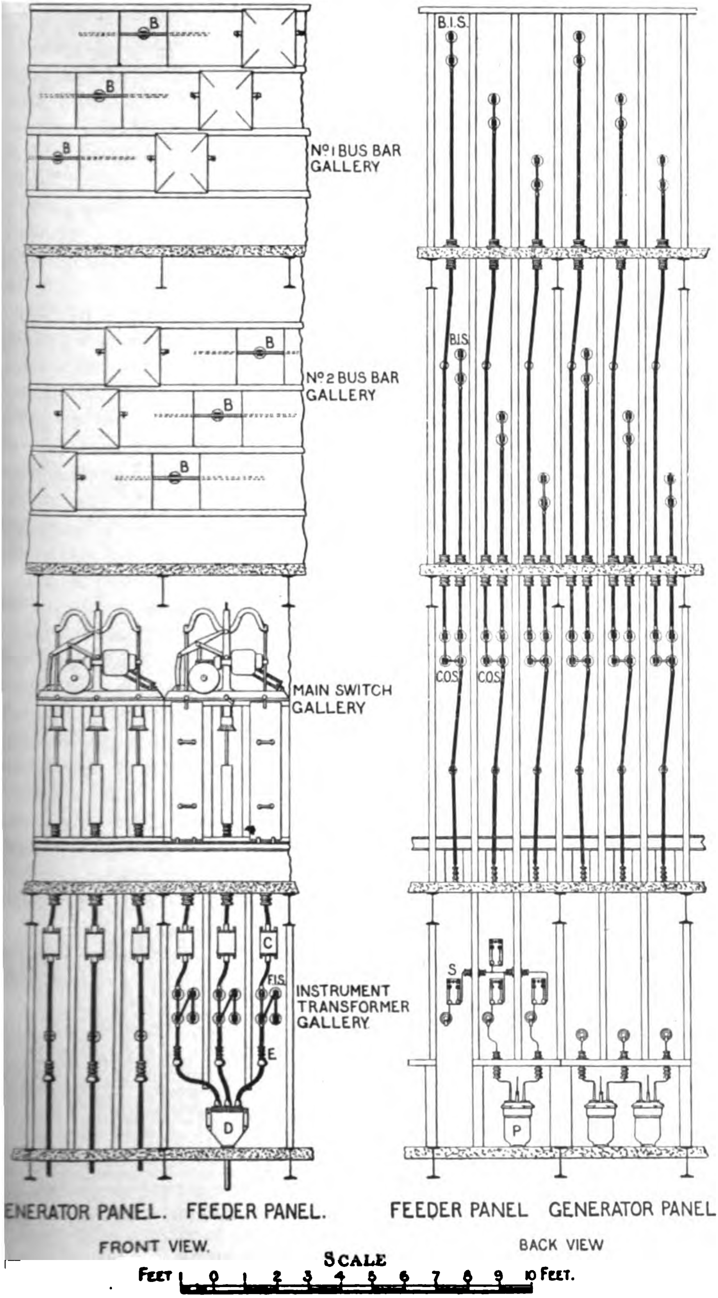
In designing the station buildings it was necessary to decide first upon the apparatus to be installed—in the case of the switchgear it is similarly necessary to decide upon the main switch, as the position of the terminals and the method of operation both affect the general lay-out of the gear. It is now recognised that oil-switches are essential, and all high-tension circuits should be broken in this way—if only for the reason that opening the circuit under oil puts so much less stress on the cables and on insulation generally.† The switch chosen should be capable of breaking any current which may be met with in practice. This practically means, in emergency, breaking the whole short circuit capacity of the station. It is only, however, within very recent years that it has been possible to secure switchgear which will meet such a contingency.

Main busbars.

The busbars, in common with other parts of the switchgear, should not depend on fibrous or other combustible insulation. They may with

* In America brickwork has been used for similar boards, but in the cases under consideration it was found that the adoption of concrete construction resulted in securing not only a cheaper but certainly, in many ways, a better job. The first board of this type was, so far as we know, erected in the Power Station of the Metropolitan Street Railway Company, New York, but there the complete subdivision referred to has been carried out in the case of the busbars and the switches only, the connections themselves are not dealt with in the same way. Obviously the cost involved forbids that similar precautions be taken in small substations. It is therefore necessary to so arrange these small substations with regard to the rest of the system that if a serious fault should occur in any one it is dealt with not by switches in the substation itself, but by the gear in the Power Station or in some large substation.

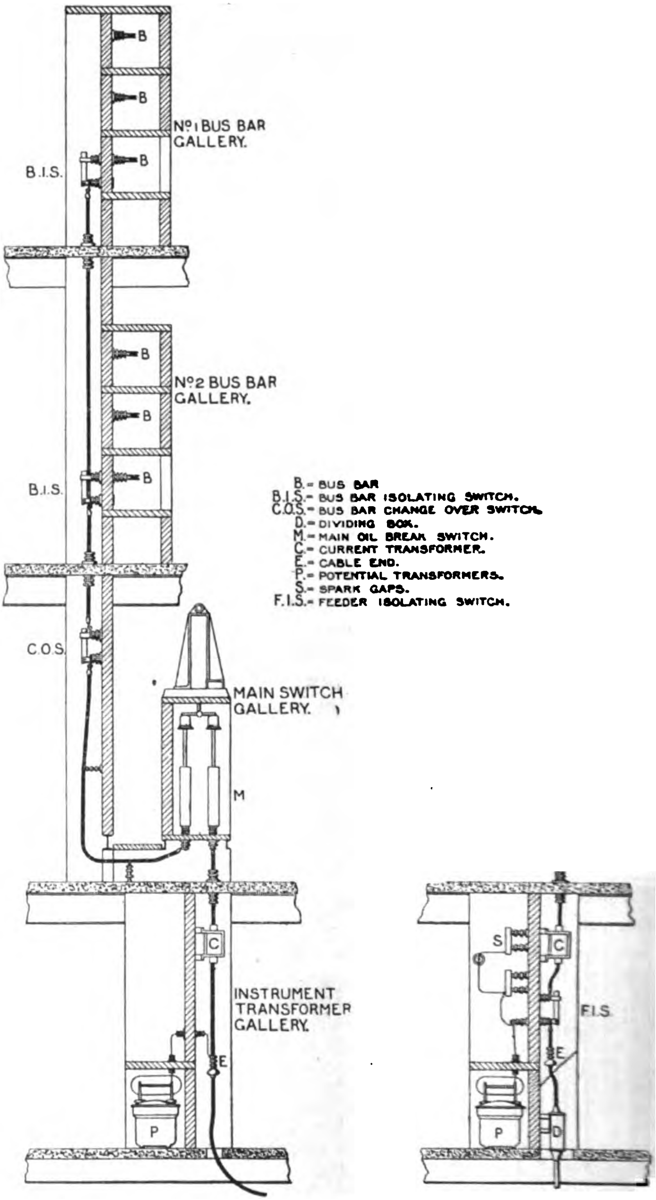
† Oil-switches were first used for high-tension currents by Ferranti in this country, and by Messrs. Brown Boveri in Switzerland. Lately they have been developed (especially for large powers) by the General Electric Company of America, and also by the Westinghouse Company.



BACK AND FRONT VIEW OF H.T. SWITCH GEAR.
CARVILLE POWER STATION

FIG. 13.

The reference table of Fig. 14 also applies to this one.



GENERATOR PANEL. FEEDER PANEL.

CROSS SECTION OF HIGH TENSION SWITCH GEAR.
CARVILLE POWER STATION.

FIG. 14.

advantage be of bare copper mounted on insulators, each busbar being separately enclosed in an independent chamber. The object of complete subdivision here, as in other cases, is to avoid as far as possible any serious trouble spreading and damaging the switchgear as a whole should the switch by any chance fail to break a short circuit.

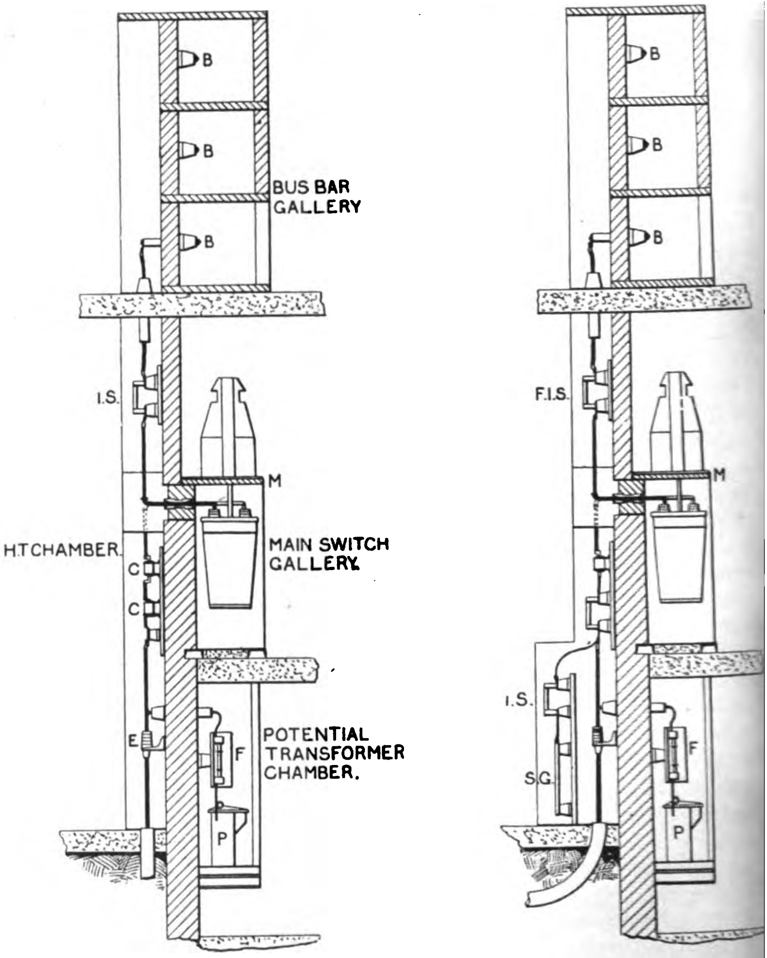
Connections to oil switches.

Obviously in order to carry out without great expense complete subdivision of the connections as well as of the busbars and switches, it is necessary to consider carefully the location of the switches in reference to the busbars, so that the former may be directly above or below the latter. In order to avoid all possible risk it is essential that the switches should be next the busbars themselves, *i.e.*, that no apparatus of any kind should intervene between the switch and the busbars. Probably one of the greatest dangers to reliability of supply and one likely to show itself prominently in the near future is the excessive carelessness with which cables connecting machines or feeders to the switchboard have in the past been cramped together indiscriminately in a trench or tunnel. If big currents or large powers are to be conveyed, whether in a Power Station or under a Motor Coach, nothing short of complete isolation (or failing this several inches or feet of air space depending on the potential and power) will ensure freedom from failure or keep the damage within proper limits in case of the failure of any part. It is not sufficient to attend to this point on the switchboard itself, it must be attended to from the machine terminals to the outgoing feeder. In the case of a Power Station it is unsafe to lay cables carrying large powers, whether high or low tension, even spaced some inches apart in tunnels or manholes, unless each cable is in its own duct, or in some other way protected by a properly earthed metal shield.* In order that these connections may be as far as possible completely subdivided, the feeder or machine should preferably be kept directly below or opposite to the main switch. Between the switch and the machine or feeder cables the various transformers for the operation of instrument and relays should be installed. (See Figs. 14 and 16.)

Instruments

All instruments should be worked through transformers, thus greatly simplifying the alternating current switchboard problem, as recording wattmeters, power factor indicators, ammeters, voltmeters, and relays can be (and should be) supplied from one set of transformers —so reducing the complication on the main circuits to a minimum. Although by the above method the main connections are not complicated by the installation of additional instruments, yet for the sake of simplicity

* Three-core cables with a complete copper shield embracing all three cores should be used for these connections when earthed iron shields are inadmissible. In both this country and the United States it was until recently the universal practice to run bare lead-covered cables in manholes, with the natural consequence that in the event of one of the cables failing it was no uncommon thing for all the cables in the manhole to get damaged. The Authors have known lead-covered cables give way due to an incandescent lamp lying against them. Arcs are frequently started between large power cables by the fusing of some minor wires—possibly pilot wires—which had nothing to do with them.



MACHINE PANEL.
(ROTARY CONVERTER.)

FEEDER PANEL.

SCALE

FEET. 1 0 1 2 3 4 5 6 7 8 9 10 11 FEET.

B - BUS BARS.
I.S - ISOLATING SWITCH.
M. - MAIN OIL BREAK SWITCH
C - CURRENT TRANSFORMER.
E - CABLE END.
F. - INSTRUMENT TRANSFORMER FUSE
P. - POTENTIAL TRANSFORMERS.
F.I.S. - FEEDER ISOLATING SWITCH.
S.G. - SPARK GAPS.

SECTIONS THROUGH H.T SWITCHGEAR,
N.E.R[LY]. SUBSTATIONS,

FIG. 15.

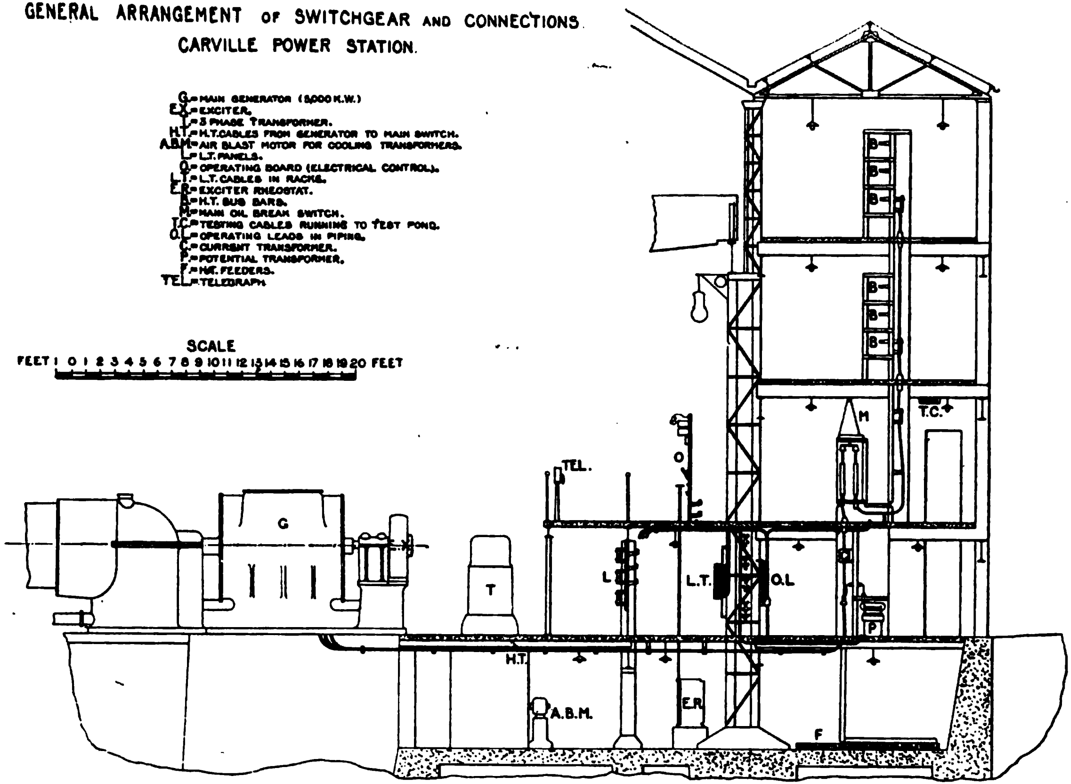

GENERAL ARRANGEMENT OF SWITCHGEAR AND CONNECTIONS
CARVILLE POWER STATION.
G = MAIN GENERATOR (5,000 K.W.)
EX = EXCITER.
T = 3 PHASE TRANSFORMER.
H.T. = H.T. CABLES FROM GENERATOR TO MAIN SWITCH.
A.B.M. = AIR BLAST MOTOR FOR COOLING TRANSFORMERS.
L = L.T. PANELS.
O = OPERATING BOARD (ELECTRICAL CONTROL).
L.T. = L.T. CABLES IN RACKS.
E.R. = EXCITER RHEOSTAT.
B = H.T. BUS BARS.
M = MAIN OIL BREAK SWITCH.
T.C. = TESTING CABLES RUNNING TO TEST POND.
O.L. = OPERATING LEADS IN PIPING.
C = CURRENT TRANSFORMER.
P = POTENTIAL TRANSFORMER.
F = H.T. FEEDERS.
TEL = TELEGRAPH.
SCALE
FEET 1 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 FEET
G
T
H.T.
A.B.M.
TEL.
O
L
L.T.
O.L
E.R.
F
P
M
T.C.
B

FIG. 16.

and saving in first cost the number of instruments installed should be reduced to the lowest limit.*

Methods of operation. The desirability of locating the machine and switch panels directly opposite their respective generators or cables has been previously referred to, but this arrangement necessarily involves a switchboard extending the whole length of the station. It is evident that the switches on such a board must be operated from some central point in the station, *i.e.*, the switches must be controlled from a distance. There are three ways of effecting this :—

(1) Electrically, as has lately been successfully adopted and developed by the General Electric Company of America.
(2) Mechanically, as railway points are now worked from a signal cabin. In this case automatic devices must be electrically tripped.
(3) Pneumatically, simply substituting compressed air as the operating agent.

There is very little difference between the three methods so far as adaptability is concerned—for reliability we prefer either (1) or (2). In each case the operating platform can be kept small so that all the gear is under the eye of the operator. In fact its length is really limited by the room taken up by switchboard instruments more than by any levers, switches, or valves necessary for the mechanical, electrical, or pneumatic operation. Generally speaking, the longer the board the more desirable does electrical operation † throughout appear to be.

Automatic devices. Under oil-switches we have referred to the necessity for opening all circuits by the switch rather than by fuses. This means that it is almost essential that automatic overload devices should be installed, so as to operate the switches on each outgoing feeder. When automatic switches first replaced fuses, such overload devices were manufactured on the same lines as an ordinary direct-current traction circuit-breaker. This design, while entirely satisfactory in the case of an ordinary direct-current traction supply, where a momentary stoppage is of relatively small importance, is quite out of the question in the case of a Power System from which not only lighting and power are supplied, but on which revolving synchronous substation machinery may be running. The shut down of a feeder means the shut down of a substation, and this is a serious matter. It was found that such circuit-breakers were apt to operate with instantaneous overloads which would have cleared themselves had pressure been maintained. In order to avoid this trouble clockwork time-limit devices were tried with equally unsatis-

* The following list gives all the instruments that are absolutely essential :—Machine Panel.—Main ammeter on one-phase, voltmeter for synchronising, field ammeter. Feeder Panel.—Ammeter on one-phase. The recording wattmeters may be put in the machine leads for the reasons stated later (p. 741); it is also safer to put the recording wattmeters on the machines than on the busbars, as the arrangement avoids any apparatus being connected with the busbars except through an oil-switch.

† It is desirable that the operating leads should be kept entirely separate from the instrument leads, and further that the leads for each machine should be kept separate and run in accessible positions.

factory results, as when the clockwork devices were set so as to keep the switch "in" on small short circuits such as were likely to clear themselves they refused to open sufficiently rapidly on bad shorts, so upsetting the whole system.

Automatic devices on feeders and machines.

It was suggested, therefore, by several engineers and manufacturers independently that what was required was an automatic device which imitated the action of a fuse; that is to say, an automatic adjustable circuit-breaker having a time lag inversely proportional to the magnitude of the overload. Various manufacturers have endeavoured to meet this condition in different ways,* but though great improvements have been effected it cannot be said that any protective device has yet been perfected which can be depended upon under all conditions on a complicated system to cut out a faulty feeder or machine without affecting the working of other apparatus. Outgoing connections from the busbars may be more or less satisfactorily protected as above, but if similar overload devices are used in the machine circuits it is practically impossible by any graduation to ensure that the feeder and not the machine circuit will open in the case of an outside short circuit, while it is equally difficult to discriminate so that the faulty and not a sound machine is cut out in the case of a short-circuit occurring on one of the generators. Endeavour has therefore been made to fit relays which would only operate with reverse current † having a time limit inversely proportional to this reverse current, but which would not respond to any overloads or shorts so long as a positive direction of current was maintained. This latter arrangement would at first sight appear a satisfactory solution of the problem, but in practice it is very far from being so. All such reverse devices so far put to commercial use depend for their action on a potential coil. It is just when the short-circuit is most severe that these devices are wanted, and the difficulty is that with a severe enough short-circuit the potential may drop considerably before the faulty machine is cut out, with the result that the apparatus fails to operate.

Another objection to the present type of relay (both overload and reverse) is that in the case of a heavy fault, when the whole of the network may be affected, the cut-outs in other substations than the one at the end of the faulty feeder operate and thus shut down supply; this is especially liable to happen on polyphase systems when the fault develops between two phases only or between one phase and earth, in this case all motors and transformers on the system immediately tend to pump current into the fault. The Authors are of opinion that at the present time automatic protective devices require more attention than any other subject in connection with Reliability of Supply.

* See "Protective Devices for High-tension Electric Systems," by W. B. Woodhouse, British Association, September, 1903.

† Messrs. Brown Boveri have developed a reverse current-circuit breaker similar in type to their overload circuit-breaker. The introduction of a reliable reverse current relay will also solve the problem of cutting out a faulty feeder from the substation end where two or more feeders feed one substation.

Low-tension Switchgear and Connections.

Hitherto we have dealt with the main board and high-tension apparatus only, the low-tension switchgear and connections may, however, represent a large part of the total expenditure on switchgear, as they control all the auxiliary apparatus, the exciting circuits, and all the lighting for the Power Station and adjoining yards and shops. The same points which have been referred to in detail when dealing with the main board and connections apply to the low-tension apparatus and cables, though of course in lesser degree. It is certainly important that all low-tension connections should be kept entirely separate from high-tension connections or cables, in order that no fault of the former may affect the latter. The Authors have a strong preference for wiring on insulators as against wiring in pipes for all small wires and for all lighting work. It is cheaper, it give less trouble in practice, and any fault is more readily seen. This system, however, can only be carried out in cases where proper subdivision is resorted to and where the circuits are not crowded together.

(6) MEASURING APPARATUS AND RECORDS.

Importance of Boiler-house records.

In general, while very complete station records are kept of the data directly affecting the electrical side of the generating plant, scant attention is paid to boiler-house records so far as the factors governing the economy of the boilers are concerned. This would appear to be a mistake, as it will almost invariably be found that the boiler-house equipment will give a greater return for any trouble taken with it than will either the engine-room or the electrical apparatus. The efficiency of the electrical and engine-room apparatus are comparatively easily ascertained by fairly accurate instruments. On the other hand, tests on the boiler-house apparatus are frequently of so rough and ready a description as to arouse at once doubts as to their accuracy, and as a consequence they are taken less and less frequently. It is, however, possible, and it is certainly desirable, to get data from the boiler-house plant of very approximate accuracy. Complete records should be kept showing the performance of the various component pieces of apparatus throughout the whole process of generating electricity from coal, and an assistant with some chemical knowledge should be made responsible for the boiler-house economy and for keeping accurate data in connection therewith.

We will briefly refer to the apparatus necessary for keeping a check on the economy of the station :—

Coal-weighing apparatus.

Coal-weighing Apparatus.—The coal-weighing apparatus should consist of :—

(*a*) A main coal truck weighbridge for checking the Railway Company and the Colliery.

(*b*) An apparatus for weighing the coal fed to each boiler from the overhead bunkers (if these are erected).

The latter may be used either continuously or for special tests. The weighbridge should certainly be used continuously.

Coal Analysis.—It is as important to check accurately the calorific value and the percentage of ash contained in the coal purchased as it is to check its weight, and an analysis should therefore be taken from weekly samples of the coal used. **Coal analysis.**

Apparatus for Analysing Flue Gases.—Records of the flue gas composition are also of importance. There are several instruments in the market for taking continuous records, but none of them seem likely to displace the Orsett apparatus. **Apparatus for analysing flue gases.**

The Measurement of Temperature.—Ready means should also be provided for obtaining the following thermometric records: Temperature of superheat, temperature of air-pump discharge, temperature of feed-water before and after economiser, temperature of flue gases before and after economiser and at various positions along the flue. **The measurement of temperature.**

Water-measuring Apparatus.—Continuous records should be kept of the whole of the feed-water, the make-up water, and the water purchased from the water company. Permanent arrangements should further be made for measuring the air-pump discharge of any one unit. This is comparatively inexpensive, yet it is to be found in very few stations. The simplest way to obtain this information is to have a two-way valve on the air-pump discharge, one way of which is connected to a special pipe leading to duplicate measuring tanks so that the discharge from any unit may be accurately ascertained for any period of test. **Water-measuring apparatus.**

Pressure Gauges.—The steam and vacuum gauges call for no remark. Draught gauges are of more importance in stations fitted with mechanical draught than they are in stations fitted with natural draught, and it is only by frequent observation that the best draught, the best thickness of fire, and the best speed of stoker travel can be maintained. **Pressure Gauges.**

Output Meters.—The wattmeters may either be placed on the main busbars between the feeder-panels, on each individual machine, or on each of the outgoing feeders. These meters necessarily complicate the switchgear materially, but it is absolutely necessary to provide them. In order that it may be convenient, without alteration to the connections, to test the output of a main generating unit at any time, it would seem to be correct to place them in the generator leads. A further advantage of this is that in a modern station it involves fewer meters than if they be placed in the feeder-cables. Power-factor indicators are only of importance where the power factor is under control, as in the case of a station having a combined synchronous and induction motor load. **Output meters.**

Having installed all the above instruments, the only item necessary to complete the equipment required for accurate special tests is a water-resistance to absorb the energy generated by the plant under test. It is worth while providing permanent arrangements for connecting this water-resistance to any generator at will.

To sum up, complete *permanent* apparatus should be provided for taking all necessary tests, thus avoiding the unreliability and uncertainty of makeshift arrangements.

CONCLUSION.

In discussing the general principles governing Power Station Design, and in illustrating their application to certain parts, we cannot pretend to have dealt with all the components which go to make up a complete Power Station, since however much the designer may endeavour to simplify the problem it still remains a complicated grouping together of apparatus. The parts of a Power Station to which we have not particularly referred are the Boiler-house Equipment and the Piping Systems. Throughout we have avoided discussion of the actual design of individual pieces of apparatus (such as the boiler, the steam turbine, or the dynamo), this being rather a question for the manufacturer than for the designer of a Power Station. The function of a Power Station designer is to choose from standard apparatus that which best fulfils the conditions to be met, and to assemble it in the most economical way. It is only by a rigid application of this principle to the individual parts that the essential condition of Low Capital Cost can be complied with.

If any excuse be necessary for calling attention (at perhaps too great length) to well-known principles, it must be found in the fact that the success of Power Supply on a large scale depends entirely upon their being correctly applied to all the component parts of a Power Scheme. Electrical Energy from Public Supply as against the provision of isolated plants is possible in this country with its relatively dense population in a way that is not possible in America or on the Continent—where industrial centres are separated from each other by wide tracts of country. Although in many ways disappointingly late, realisation during the next few years of our almost unique position in this respect is likely to have a marked effect both Industrially and Socially.

Mr. Barker. Mr. JOHN H. BARKER: There are several remarks I should like to make, although it is somewhat unfair perhaps to call on a turbine man to speak first, for after the advocacy of turbines which we have heard from Mr. Merz, I should rather have listened to an advocate of reciprocating engines. I have lived in Newcastle for many years, and have followed with great interest the development of the Neptune Bank Power Station, and also of the one at Carville; further, I had the honour to be connected with the installation of the first turbine at the Neptune Bank Station. To follow the paper in order, the first thing I notice is Mr. Merz's love of alternating current. He was reared in it, and has stuck to it, but I have always been surprised that he has not maintained it throughout in his distribution system, instead of putting down what I and many more have always disliked, the unnatural production, direct current. Mr. Merz credits manufacturers with getting £10 per kilowatt for their engines and dynamos. Alas, they were happy days for the manufacturer which will probably never recur. Six pounds is a very good figure for even so small a size as 500 or 600 k.w. Now we come to an important point, and I am sorry to see that "Chesterfield, Junr." is not

here to-night. I should have liked to ask him to put back into his valuable table the cost per kilowatt of plant installed, or per kilowatt of maximum demand. It is a thing that certainly Town Councils lose sight of, and this is the first paper in which I have seen so much stress laid upon the most important point of the actual cost per unit for interest and redemption. None of us know, and the Town Councils least of all, what the amount of redemption should be at the end of, say, fifteen to twenty years. I also agree with the authors in their partial condemnation of the labour-saving apparatus. Automatic stokers have almost come to be regarded as an essential part of every power-station. So long as the consumption of coal is not more than the capacity of a man, it seems to be a great mistake to put in an apparatus in which all the coal is lifted twice the height of the furnace into a hopper to be fed automatically on to the grate. I have always found that the supply of firemen is adequate, and their capacity is certainly a ton or a ton and a half per hour; good men can get much more steam out of any boiler than the best automatic stoker that has ever been made. This and another point in the paper reminds me of a remark of a late chief engineer under whom I sailed at sea. He said, "Let your engines go—to a place which is warmer—but look after your boilers," a point many of us omit to do; we prefer to stay by the cleaner engine-room and let the blackhole take care of itself. Recently I have had occasion to compare somewhat closely the types of generating plant, the reciprocating engines and turbines, and I am delighted to think that the engineer who represents what was the most exemplary reciprocating station should now be one of the most strenuous advocates of the turbine. In the early days of the turbine every engineer said, "Look at Newcastle; they have a turbine station and a reciprocating station there," and disparaged the former. Now what is the result? After fourteen years both are turbine stations, and the reciprocating station is now the bigger turbine station of the two. That is a score for turbine builders, which should not be lost sight of. I remember with great pleasure ten years ago, when I was in charge of the second turbine station built, Mr. Merz came to stay with me. We had a pleasant week-end, and may I flatter myself that the turbine seed then sown has taken root and brought forth such a magnificent crop? Mr. Barker

There is a figure of steam consumption given on p. 706. It states "Calculated steam per kilowatt-hour." I am rather at a loss to understand what calculated steam is. I have plotted these figures, and I think justice is hardly done to the turbine. This particular turbine was nominally for 1,500 k.w.; it has since been worked at a capacity of 2,000 k.w.; the published units are only at the lower power. I have drawn this curve further to the 2,000 k.w., and it then comes down to close on 16 lbs. of steam per kilowatt-hour. The curve shown on the wall is drawn under one of the points, which results in its coming almost flat at 1,450 and 1,500 k.w. I should like to ask what is the amount of power that is calculated to be needed for moving the immense volume of circulating water that will have to be conveyed from the river to the Carville station. That must be very great, and

Mr. Barker. perhaps the authors would give us some figures on that point. There is one more question. Mr. Merz has been to Chicago, and has seen this Curtis turbine: can he tell us what it is actually doing? We have heard a good many things about it; one they are going to run at lower speeds than Parsons, but the only one published runs at exactly the same speed. The results at certain vacua are slightly better, and at other places they are infinitely worse.

Mr. Rosenthal. Mr. J. H. ROSENTHAL: I think this paper is one of the most practical papers I have ever listened to, because it sums up the position of the appliances for producing electrical energy to-day, and, properly speaking, I think the paper should be entitled "How to do it." Certainly I think the thanks of every one connected with the Institution and connected with the industry are due to Mr. Merz for the manner in which he has summarised the real points of consideration in power-station design. Carville was the first installation to my knowledge in which an effort was made to bring the cost of the installation down to the lowest possible limit consistent with good and durable appliances, and I think, as a business man, that that is a matter of very vital importance to the electrical industry. I do not know whether the author is aware of it, but his design has found a good many imitations. Probably the most important plant of the kind that is being erected at present is that of the new station of 20,000 kilowatts for the supply of the energy to the Metropolitan Railway in Paris. The arrangement there is practically identical with Carville, the only difference being that the economisers are arranged in a floor above instead of in line with the boiler-house. As far as parts are concerned upon which I am competent to speak, I should like to mention that I regard the steam-pipe design at Carville as a very practical and satisfactory one, and I think it will not be long before the importance is recognised of designing steam pipe plants so that there are practically only a few parts in them, and that they consist of the fewest number of dissimilar parts, and, as the station is supposed to run for ever without stopping, it is a comparatively easy matter, without in any way affecting the output, to take down a portion and replace it, and test the portion that is taken down, just as it is necessary occasionally to test a steam pipe on board ship.

Major-Gen. Webber. Major-General C. E. WEBBER: I have very little to say on this particular part of the subject. The great subject of power distribution is now becoming a burning question all over the country. My investigations have been carried out more as regards distribution, to which Mr. Merz's paper gives little attention. I should like to remind him that three or four years ago he gave evidence before a Parliamentary Committee that the station which was then in course of erection at Newcastle would cost about £20 per kilowatt output, and I do not find in his paper any complete justification of that figure. There is no doubt that there are great advantages in the position which he has selected; he is there free from almost all the difficulties of annoyance from vibration, smoke, and other things; but I think it would be interesting to us all if he could, without revealing unduly the financial position of the undertaking with which he is interested, and which he has described to us, give us some idea as to what is the cost

per kilowatt of the station now, and when it will be completed to its full capacity. I think that the most interesting part of the subject, which I hope will be discussed at another meeting, is as regards the cost and mode of distribution, on which I hope Mr. Addenbrooke will give us a paper. One of the most suggestive and most ably put together parts of the paper is p. 739. There he refers to a subject which must be of great interest to all engineers who are connected with large distributions at high tension, that is the difficulties that have not yet been overcome, and to which the engineering minds of our Institution will have to turn their thoughts. That those difficulties are only referred to in a limited degree on that page is evident to any one who has had to deal with troubles from "shorts" arising in switchboards and in mains. I do hope that all who are present, particularly all the younger engineers who are studying the subject, and who are looking forward to distinguishing themselves, as I hope many of them will, when they become attached to power-stations, will read that page and ponder over it well; and when an opportunity comes, that they may have the chance of providing means for successfully overcoming those most serious difficulties which are bound to be encountered in the future of great power-distributing systems. Major.-Gen. Webber.

Mr. G. L. ADDENBROOKE: This paper raises so many important points that it is difficult to know which to select to speak on. But I think we must all congratulate Mr. Merz very much on the lines he had taken in this paper. Speaking generally, I am sure that every one who has worked at power work for any length of time must agree with almost everything he says, so that as a matter of fact there is very little to criticise. I am very glad to see that the author at the outset has drawn attention to the point that electric power supply is a commercial undertaking; and it is a commercial undertaking in a greater sense than many of the large undertakings are which are described from time to time in this room. In waterworks, and even in electric lighting stations, and so on, commercial considerations are very important; but there is this point about many engineering undertakings, that you can adjust your prices to the costs you must necessarily incur in carrying out the work; but in electric power supply we are trying to replace something else which already exists, and there is no question of sentiment or anything else about it. If you cannot supply the power at a price which gives advantages over local generation or generation in any other manner, the power-station will not get any business, consequently the whole undertaking is absolutely on pure commercial lines. From this standpoint, as Mr. Merz has so clearly pointed out in the diagram, capital cost plays an even more important part than works costs. The longer one works at power work, the greater attention one sees must be paid to capital cost. In that connection the turbine is coming in as a great help to those who are engaged in this class of work. There is one point in connection with power-station design and location which Mr. Merz has not dealt with, probably because he has had so many other points to consider, namely, the question of condensing water. On steamers, which carry the class of engines which require big condensers at present, water is always at hand; but it is Mr. Addenbrooke.

Mr. Addenbrooke. really astonishing what a serious matter it becomes when you have to think of providing the condensing water for a large power-station. For instance, a power-station of 10,000 kilowatts requires something like 1,000,000 gallons per hour when working at full load, and even if you happen to be near a river the arrangements which require to be made, especially if it is a tidal one, often necessitate a great deal of care and attention. Turning now to Mr. Merz's curve, there are just one or two points which I would like to refer to about it. He takes a coal line, which you notice, and draws that right across. I think a little greater accuracy would have been secured by making that a somewhat sloping line. I do not know that it is a very big difference with coal at 6s. a ton, but when coal becomes more expensive it should be higher at the low power-factors. Then, again, in applying this curve, it must be remembered that, so far as I can see, Mr. Merz has not included administration. Of course, administration in public companies is a delicate point; but members who take the costs from this curve should remember that, as far as I can see, the items for administration, rent, taxes, etc., are not included, and in a power-station scheme, where people cannot work for nothing, and where we must have a Board of Directors, they amount to an appreciable sum. I would further like to ask Mr. Merz whether this table of costs is intended to cover units generated or units sold? That is a very important matter when you come to consider costs, and in a great many cases the difference is not always given. I would like to say a word about gas engines. I have had something to do with a power-station in the South of England, where coal is much more expensive than in the North, and where, therefore, the value of gas engines would have been greater. I had very carefully to go into their relative costs. The only saving you make by using gas engines is in your coal bill. As regards capital costs, as things stand at present, they would be rather greater than for a steam station; the labour and administration and all other things are practically the same. Therefore it comes down to the point of the saving in coal. Supposing that the saving of coal is realised which the gas engine people tell us they can effect, the result on a power scheme such as Mr. Merz is putting before us would be something like this, I think; it would make about 8 per cent. difference in the price at which you could supply to the consumer for ordinary load-factors, or, if you could keep the price to the consumers at the same figure, it would make about 1½ per cent. difference on the dividend that you could pay. That is about what we can get from gas engines. Supposing that they will do that, and that gas producers will do (which is another important matter) all that their advocates say they will do at present, you see it is not a very big thing, and when you come to places where coal can be got at 6s., or even less, a ton, it is pretty clear that there is not a very great opening for gas engines in the immediate future; and therefore I think people who put down steam can feel confident that they will not have to alter their plant for a very considerable time. There are a few other remarks I might have made, but I will not take up the time of the meeting.

Mr. Lupton. Mr. ARNOLD LUPTON: I should like to ask the author of this very valuable paper if he would kindly fill up the balance-sheet on p. 709

Mr. Lupton.

with regard to the gas engine and the turbine. The cost of the fuel as shown on his diagram, Fig. 1, 0·15 of a 1d., is not such a very large item; if it could be reduced to nothing of course it would be a great improvement. The author is no doubt well aware of the claim of certain gas generators that they can reduce the fuel charge to nothing, that the sale of by-products equals the cost of the fuel; that is the claim made. No doubt the author has investigated it, and will give us the advantage of that investigation; one would like to have that knowledge. Of course the fuel consumed in the gas engine is half the amount shown on the diagram Fig. 1; instead of 0·15 of a 1d. it would be 0·075. If there is a sale of by-products which equals the cost, then the fuel is no cost at all. The author has dismissed the gas engine, however, entirely as being unworthy to stand in competition with the steam engine, because he suggests that it will not do the required work. Of course if that is so, that settles the matter; but then I am aware of great firms in the North of England, firms whose names appear to me very eminent, who are prepared to guarantee that the gas engine will do any work that any steam engine ever has done or can do. That is what they, in effect, are prepared to guarantee. Mr. Addenbrooke says that the use of the gas engine will increase the dividend 1½ per cent. It seems to me that whether you pay 4 per cent. or 5 per cent. just makes all the difference between success and failure. I hope the author will add to our obligations to him by kindly filling up that balance-sheet.

The President.

The PRESIDENT announced that the scrutineers reported the following candidates to have been duly elected:—

Associate Members.

John L. Andrews.
Arthur R. Bacon.
Claude E. Crocker.
Thomas A. F. Cutler.
Malcolm T. Evans.
John T. Fahy.
Thomas Humphreys.
Edward B. Mulliner.
Hubert H. Nash.
Henry P. Onslow.
Chas. L. De W. Reader.
Wm. Grimshaw Stones, A.M.I.M.E.

Associates.

Alexander W. Brown.
James Caldwell.
Horace S. Davies.
Septimus Gillitt.
Arnold S. Hughes.
David L. Mitchell.
Stuart Roseveare.

Students.

A. Adams.
Joseph N. Aitkin.
Alfred Ardern.
Chas. F. N. Atterbury.
William M. Berry.
Frederick S. Bowen.
W. Forbes Boyd.
Alec W. Brydon.

Students (cont.)

George G. Bullmore.
David Burns.
Hugh Burroughes.
Wm. Daunt Busteed.
Harry Butler.
Arthur F. N. Chandler.
Krishna C. R. Chowdry.
Wm. Galloway Conner.
Herbert Coope.
Arthur L. Coward.
Francis W. Crawford.
Frank Crompton.
Chas. E. Crowther.
James Grimshaw Cunliffe.
Richard G. Cunliffe.
W. G. Cunliffe.
Claud J. Elliott.
Arthur G. L. Evans.

The Four Hundred and Eighth Ordinary Meeting of the Institution was held at the Society of Arts, John Street, Adelphi, on Thursday evening, May 5th, 1904—Mr. ROBERT KAYE GRAY, President, in the chair.

The minutes of the Ordinary General Meeting held on April 28th were, by permission of the meeting, taken as read, and signed by the President.

The names of new candidates for election into the Institution were taken as read, and it was ordered that they should be suspended in the Library.

The following transfers were published as having been approved by the Council :—

From the class of Associates to that of Associate Members.

John Thompson Hayes.	Sarsfield William Martin.

Messrs. H. Brazil and C. K. Falkenstein were appointed scrutineers of the ballot for the election of new members.

Donations to the *Library* were announced as having been received since the last meeting from Messrs. A. S. E. Ackermann and C. C. Hawkins; also from the President, Mr. R. K. Gray, who had purchased the late Mr. W. G. McMillan's collection of scientific works and presented it to the Institution; and to the *Building Fund* from Mr. M. M. Gillespie, to all of whom the thanks of the meeting were duly accorded.

The PRESIDENT: We will now proceed with the discussion on Mr. Merz's paper. I would like to say before the discussion commences that we are favoured to-night with the presence of Mr. Insull, who comes from Chicago. He is a member of the Institution who went from the Old Country to the other side to teach them what to do, but he rather likes the Old Country, and we are glad to see him here this evening. The President.

Mr. B. M. JENKIN: I think the paper is particularly interesting to the consulting engineer, as it deals with the design of central stations from his point of view, and in some ways it is a peculiar point of view. Taking some of the points in order, I notice that Mr. Merz suggests that it may be desirable to consider the possibility of removing your generating station as the system grows. I should have hardly thought it was possible to take this into account, as the laying of high-tension feeders for supplying the system would make the change in location of the station a very expensive matter indeed. The Mr. Jenkin.

Mr. Jenkin. lifting of high-tension feeders and relaying would, I imagine, make it almost prohibitive. It is interesting to note that the results arrived at by Mr. Merz in his paper are very similar to the results arrived at quite independently with different generating plant. The authors speak here entirely of the design of stations with turbines, and the design that is best suited if turbines are adopted. They mention particularly the desirability of dividing the station into groups or units. In this one quite agrees with them, but I should hardly like to go as far as they do. I gather that they suggest each generator should have its own group of boilers, and they almost suggest that it is not necessary to even connect the different groups of boilers. With this I hardly agree. It seems to

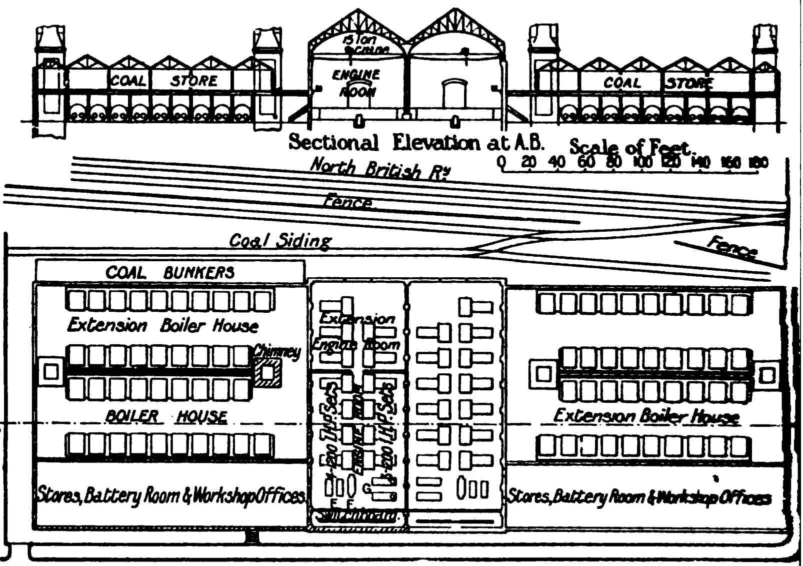


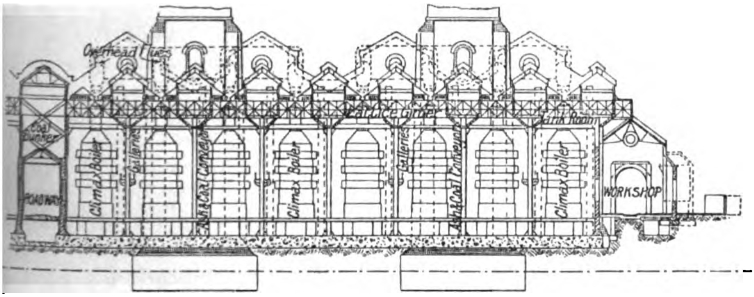
FIG. I.

me it is quite right to place the boiler-house as they do at right angles to the engine-room; it keeps the boilers close to the generators and makes a simple arrangement of pipe work. This is the arrangement that Dr. Kennedy adopted in designing the Edinburgh McDonald Road station in 1898. I have put a Fig. I on the wall, showing the general arrangement of this station in plan.

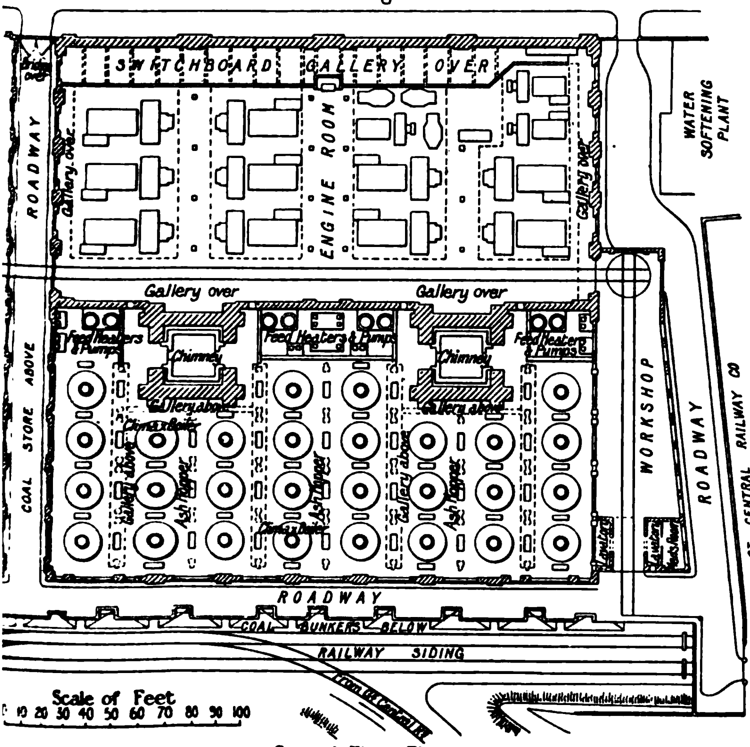
You will see the centre part of the building consists of two engine-rooms, the one at present erected is shown with a number of engines in it, and it repeats exactly on the other side. There are two boiler-houses for the first engine-room, and two for the extension engine-room. In this way the whole station is duplicated when the extensions are built. This arrangement puts the two engine-rooms in the centre of the building and the boiler-houses to the outsides. The two switch-boards are end on, so that the control of the generating plant is well centralised in the building. The chief difference from Mr. Merz's

design is the arrangement of the chimneys. In designing a station to be built in a town, you have to deal with the exhaust steam if you are not condensing; you have to take the exhaust steam up the chimney, and that renders it desirable to put the chimney near the engine-room; where you condense it does not very much matter. Mr. Jenkin

It seems to me that the grouping of the plant into units is undesirable as regards the boilers; you should be able, I think, to change from one



Transverse Section through Boiler House



Ground Floor Plan.

FIG. J.

Mr. Jenkin. generator to another at a moment's notice should you notice anything wrong, and it should not necessitate changing from one set of boilers to another; the boilers that are generating steam should go on steaming regardless of what generator is running. Later in the paper the authors suggest that the auxiliary motors required for any unit of plant should be coupled to the generator of that unit alone and not to the switchboard. That would mean that when you shut down the generator the whole of the stoker and pump motors would be stopped. There, again, you get into a difficulty if you want the boilers to go on steaming when you shut down the generator. I think it would be better to keep the boiler-house complete in itself and independent of the generators. There is something to be said on both sides; but there is certainly much to be said for not coupling them entirely in units. The grouping of the station, repeating the boiler-house, and possibly the engine-room also as shown in Fig. I, has great advantages, and helps to prevent the spread of fire, etc.

I have shown in Figure J a station of some interest, designed by Dr. Kennedy and Mr. Dobson, for the Central Electric Supply Company. It contains three-phase high-tension plant, but no condensers. There you have Climax boilers, and the diagram shows how they can be arranged in groups, repeating. There are four rows of engines in the complete engine-room, with the switch gallery along one side of it, and the boiler-house along the other side. There will be finally three squares similar to the one shown on the figure, with six chimneys in all. The design was worked out so as to use to the best advantage a long narrow site. You get the bunkers at the bottom of the figure, beside the sidings, the coal conveyors going straight across the boiler-house to bunkers over the boilers. The steam pipes go across from the boilers to the engines; the leads go straight from the generators to the switchboard, so that you need not cross any of the leads and steam pipes, and really you obtain exactly what Mr. Merz describes as so desirable in his arrangement. The generators are next to each other, and all the leads go up the centre aisle, and the steam pipes outside; you have a long switchboard running parallel to the boiler-house exactly as the authors have, but in Fig. J you have reciprocating engines instead of turbines. You arrive at a very similar design, however. I do not know whether one ought to describe that boiler-house as being at right angles to the engine-room or not; when you get to circles for boilers it is a little difficult to say; but as regards the steam pipes and main leads, the arrangement is really very similar to that in Mr. Merz's design, and I naturally think it is a good one.

I have put up the diagram of another station (K), which is also a three-phase high-tension station but with condensing plant. A very similar design to Fig. J is adopted, but the engines, instead of being placed with the alternators face to face, are placed with the engines back to back, with the condensing plant and circulating pipes between the engines; the steam pipes are run along in the centre bay above the condensers. The high-tension leads run up the sides of the building to the switchboard, which runs along one end of the engine-

Mr. Jenkin.

room but parallel to the direction in which extensions are made. Each boiler-house is at right angles to this direction as in the authors' design. The whole station is repeated again and again as necessary and it can also be duplicated, as the site allows of it, on the other side of the coal bunkers and sidings, so that you get the coal bunkers in between, with conveyors feeding into the boiler-house on each side of it. This means that you can duplicate the station in both directions up and down the paper and across it. The provision of spare plant is a most important consideration, and I think the authors, perhaps, have not fully emphasised the importance of having sufficient spare plant. Not only is it necessary to have a spare set to take the place of any generator that may fail, but to have a spare set which you can overhaul and entirely take to pieces, and at the same time have a spare set that can take the place of any one that breaks down. That means practically two spare sets. The authors, I gather, deal with this by giving the plant a large overload. That is another way of dealing with the thing, but where the units get too large and you have not a sufficient

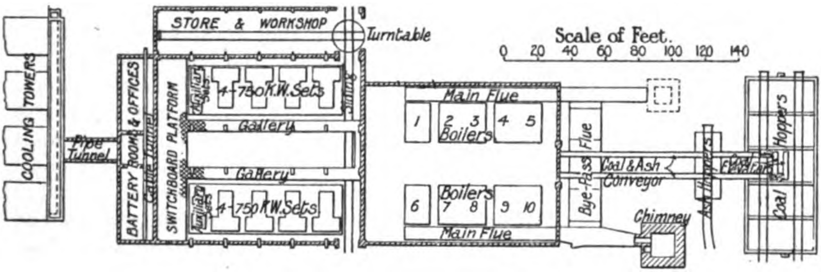


FIG. K.

number of them, it may be a dangerous practice to have only one spare set.

With regard to the switchboard, I feel that the authors deserve our thanks very much for having shown how carefully this should be designed, and that it really should be given space. I am glad to see that they have had courage to give the switchboard sufficient room. I think most of us have been misled by the practice with low-tension boards, where a narrow gallery was sufficient, and we have tried when designing three-phase boards to put them on the same sort of gallery as that on which we put a low-tension board. That is quite impossible. You must have sufficient room to separate your leads and get them properly arranged and have big switches. The only point in connection with their switchboard with which I do not entirely agree is the arrangement of selector switches, or, I think they call them, 'bus-bar change-over switches. They have two sets of 'bus-bars, and at the back of the board a switch by which they can couple any feeder or generator to one or other set of the 'bus-bars, but from the controlling board on the gallery there is no means, as far as one can tell from the sketch in the paper, of knowing how those change-over switches

Mr. Jenkin. are set—that is whether any generator is connected to the top or bottom set of bars. To find this out it would be necessary to go to the back of the board and actually look at the switches. This, no doubt, can be very easily dealt with by arranging a system of signalling, but I think it is of importance that the switchboard hand should be able to tell exactly how the switches are set. The other point is the question of electrically controlling the main switches. It seems to me to be extremely well worked out in this case. Mr. Merz showed me all over this station, and I was very much impressed indeed with the way it has been done; but I do feel that if mechanical control of the main switches could be obtained by levers it would be a simplification. You would then keep the different switches entirely separate, whereas if you use electrical control for the switches you are rather at the mercy of the electrical supply for controlling those switches. For instance, if you control them with a battery somebody may drop a spanner on your battery, or break a cell, or do something or other, and for the time being, until it was noticed, you would have lost control of the whole of the main switchboard. If you could adopt a mechanical connection, that would be practically impossible. It is a small point, but it is worth considering. Of course with a very long switchboard like that it becomes difficult, no doubt. With regard to the automatic devices for high-tension work, I sympathise with the authors in that respect. It is extremely difficult to know what to do. One cannot get an automatic that has sense, and that is what we want. I am glad to say I saw tests on a low-tension reverse-current automatic the other day which seemed to fulfil all the requirements you could wish for. It would open with a small reverse current as long as the voltage was kept up; as the voltage was dropped it would still open the circuit, and even when there was no voltage at all across the voltage coil, the switch would still open with reverse current of under 600 amperes. It was a 600 ampere cut-out. I put 2,000 amperes on to it in the working direction, but it did not open as a maximum cut-out, and even with no voltage in the shunt coil it would still not open with any current up to 2,000 amperes in the working direction. That seems a low-tension reverse-current automatic which is exactly designed to give what we want. If we could get a similar cut-out for high-tension work, I think it will have gone far to solve our difficulties in this kind of work.

Mr. Cowan. Mr. E. W. Cowan: The few remarks that I wish to make will be confined to the part of the subject dealing with the switchgear. The authors say that it is now generally recognised that oil break switches are essential. I quite agree with that, but at the same time I regret, for some reasons, that that should be the case, because oil break is not an ideal form of break under all circumstances. In the first place, an obvious objection is that the oil, being of a highly inflammable nature, may, owing to bad contacts within the switch, rise to a high temperature, near the flashing point. Again, if the switch fails to open the circuit, the fact that the arc formed would be fed by the oil vapour renders it of a very much more destructive nature. It has been found by experiment that an arc, under certain conditions, between metal electrodes, when it was interrupted would not restart unless the current was switched on again

Mr. Cowan.

within a space of time amounting to $\frac{1}{37000}$ of a second; but in the case of cored carbons an arc formed under similar conditions could be re-established after a lapse of time of as much as ¼ of a second. I consider that an oil vapour-fed arc is somewhat similar to the arc between cored carbons, and under those conditions the arc is not likely to extinguish itself, but to spread and cause disastrous destruction. On the other hand, of course, the oil switch has certain great advantages. It is compact, and it is, on the whole, a reliable way of breaking circuits of high pressure and of heavy load. Again, it tends—and this is a very important point—to open the circuit at zero current; but though it tends to do so, I think it is doubtful whether it can always be relied upon to do so. If it could always be relied upon to do so, there would be every reason for its being permanently established as an ideal switch. I always regard the breaking of an arc under oil as being due largely to the heat-absorbing power of the oil robbing the arc of its heat, and thereby extinguishing it. In fact that the function of the oil is very similar to that of the wire gauze in a Davy safety lamp. On the other hand there is also, of course, the interposition of a non-conducting layer of oil tending to sever the arc, which is a purely mechanical effect, but I am inclined to think that the temperature effect is the chief one. Undoubtedly the temperature of the arc is lowest at zero current, and therefore one would expect the arc to be extinguished at zero current under that condition. The same applies to the mechanical effect of the oil severing the arc, because it would tend more probably to sever it at zero E.M.F. Ninety-nine times out of a hundred an oil break switch will break the circuit in a satisfactory way, but sometimes they work quietly, occasionally with a report more or less explosive, and sometimes they fail, not only in this country but in America, to open the circuit. That seems to me to indicate that they cannot always break in the way they undoubtedly tend to do at zero current, and it is therefore a serious objection to that type of switch. If the arc is broken at mean current, the mischievous effect of breaking a current on an inductive circuit would be the same with alternating current as with continuous current, and if it broke at maximum current the effect would be much more mischievous. The ideal switch would be one which gradually reduced the current to zero before opening, and did that without the intervention of a drawn-out arc. It is a well-known fact that the drawn-out arc is intermittent in its nature, and causes rises of pressure due to resonance and so on in the circuits. A method of opening a circuit out of oil without the formation of a long arc would be to magnetically blow it out. The horn break switches so much used on the Continent are really single-horn magnetic blow-out switches. The arc tends to be repelled up the horns by the field excited by the current. The arc rises also to some extent due to the levity of the gases surrounding it, owing to their increased temperature, but the main effect is the repelling action of the field. But with that form of switch you get a tendency to break the arc at maximum current. The field is at a maximum when the current is a maximum, and the field, linking the arc itself, which is repelled by the main field, is also then at a maximum, and therefore you

Mr. Cowan. get the objection that the circuit tends to be opened when the current is heavy. Instead of having the horn break, you could multiply the turns and obtain a switch which would extinguish itself rapidly and instantly by means of a magnetic blow-out if it were not for that objection. There is one other form of switch which was used a good deal at one time in this country, and which has a good deal to recommend it—I refer to the type which quenches the arc under water. This type has been used with great success in many cases, but I quite admit there are difficulties in adopting it with high pressures and in cases of high load, owing to the conducting nature of the water, and also to the fact that the water needs replenishing. I have not noticed any reference in the paper to the charging of mains. No doubt the authors attach due importance to that, but I should like to say that I consider the gradual charging up of the mains is a very important matter to be provided for in all high-tension systems, and especially in the case of extra high-tension systems. With regard to automatic contrivances, I am afraid that very often engineers specify and purchase automatic apparatus from the point of view of saving labour. The object of automatic gear is really to increase the reliability of service, and not to save labour. It is quite true that it may result in further unreliability if the automatic apparatus is badly designed or is badly manufactured. But, on the other hand, it may also result in unreliability if it is not properly cared for and inspected. We find that in central stations the boilers and engines are properly cared for and inspected, but the automatic apparatus and switchboard are very often, in my experience, neglected from this point of view. The man who condemns automatic apparatus simply because it is automatic is very much to be found fault with. He perhaps does not recognise that all the instruments on his board are automatic, and that the watch in his pocket is automatic, and it is only really a question of treating the apparatus properly. I should like to mention in connection with automatic switches, on the question of priority, that I think some recognition is due to Mr. L. Andrews for the work he has done in connection with the reverse cutout for alternating-current generators. I know they have been used for continuous-current generators for a very long time, but I believe I am right in saying that Mr. Andrews was the first in this or any country to use reverse-current apparatus for alternating-current generators and transformers in parallel. On the question of general design, I feel there is no doubt that the transition which is referred to in the paper, in connection with remote control and isolation of switchgear, is a move in the right direction, but it is of the greatest importance that that isolation should be sufficient. Many engineers do not quite seem to realise the terrible effect of a breakdown of an oil switch, and the spreading effect of the destructive arc. You should enclose the oil break switch not in a slate slab arrangement, or asbestos slate or stone, or anything of that sort, but in a substantial brick chamber, with a proper iron door ; the materials should be of such a nature that they can stand the resulting electric furnace temperature for an appreciable time. It does not do to put all one's eggs in one basket, not even if it be of the cellular type, in switchgear. I am sorry to find that some engineers

are now purchasing extra high-tension switchgear in which the break-down of one part of the switch apparatus is bound to spread, and interfere with the working of neighbouring apparatus. In conclusion, I should like to remark that I notice that both the designs of switchboards which are shown are, in essential parts, of American design. I find no fault with them on that account, but I do venture to ask that engineers in this country who have to deal with the specifications for high-tension switchgear should give encouragement to British manufacturers to this extent—that they should give consideration to their designs. I quite understand that the clause which one often sees in specifications, that no switchgear can be considered from any maker who has not actually carried out exactly similar work, is a very businesslike clause to introduce for a business man, but in the case of the expert buyer I think something more might be expected of him, and that he might be open to give consideration to such designs as have been made by British designers and British manufacturers. Mr. Cowan.

Mr. A. H. DYKES: In reading the paper and comparing the station as outlined therein with the stations to which we were accustomed only a few years ago, there are two points which strike one at first sight as embodying radical changes, namely, first of all, the development of and the increased prominence that is given to the switching gear; and, secondly, the way in which the introduction into Mr. Merz's Carville station of the steam turbine has modified the arrangements of the boiler-house. If you compare, for instance, the plan of the Carville station with that of any other well-known stations, particularly with those we put up a few years ago, you will notice how much smaller the engine-room is, compared with the boiler-house, and the different way in which the boilers have to be arranged on account of the difference in space taken up by the turbines, as compared with that occupied by the old reciprocating engines. I think there can be little doubt that the future for large stations lies with the steam turbine or with the internal combustion engine. Mr. Dykes.

Passing on to the question of the gas engine, I venture to think that in giving the pros and cons of the gas engine on p. 708, the authors have not quite, perhaps, done justice to it, for the reason that in considering gas engines you must not only compare the gas engine with the steam engine or steam turbine, but you must compare the auxiliaries, the gas generating plant, with the boiler plant. It is quite true, I suppose, that everybody at the present time is in the condition that they are rather feeling their way with gas plant. We all have a feeling that in the future the gas engine will play an increasingly important part, but everybody is a little bit doubtful about it at the moment. But, taking the points which the authors give for and against the gas engine, the fact cannot be overlooked that the fuel costs greatly diminish by using the gas engine, not only a smaller amount of coal being consumed, but there is also the saving which, under certain conditions, can be obtained by making use of the residuals. At the present time I am putting down a station of about 1,000 H.P., with a plant consisting of four 250 B.H.P. gas engines and producer gas plant to use bituminous fuel; and there the guarantees, under fairly heavy

Mr. Dykes. penalties, come out at 1·63 lbs. per k.w.-hour, with the very cheapest form of fuel. So that, even with comparatively small units of 250 H.P. apiece, the coal consumption has been brought down to an exceedingly low figure. Then the authors say the labour costs with the gas engine are high. That is true. The labour cost is higher than with a steam engine or steam turbine, but, on the other hand, the labour costs in the producer yard are very considerably less than in a boiler-house, and that also must be taken into account. The question of high cost of repair is a point which every one would probably like to know a little more about, but we hope in comparatively a few years this item will also be considerably reduced. Then, as regards high capital cost, there is no doubt that during the last few years the cost of gas engines and gas plant has been coming down very considerably. In the plant I referred to a moment ago, the cost of the engines and generators, including the whole of the pipes and accessories, starting gear, cooling water, in fact everything with the exception of the foundations and house, work out at £13 per k.w., and the total cost, including the producer, works out at £18 per k.w. This includes all accessories, and, in fact everything, with the exception of the builder's work, so that for a small plant of that size it is beginning to compare favourably with steam plant even on the score of capital cost. It is necessary to remember what the saving is as regards building. You not only do away with the chimneys, but you also do away with the whole of your boiler-house. For instance, the cost for buildings for the above-mentioned producer plant was £350, which is very small compared with what it would have cost to build a boiler-house and chimneys, and set your boilers. In a station employing gas engines, too, you would naturally utilise the heat of the exhaust and the cooling water. It may be of interest to state the way in which it has been done in this case. We have, in addition to the gas plant, to run several large boilers. We carry the exhaust out in a brick and cement lime trench, through which we pass the whole of the boiler feed, and thus the greater part of the heat in the exhaust is utilised. Turning to minor points in the paper there is one question upon which I am not quite in agreement with the authors. Under the question of gas engines they refer to the overload from which it would appear that there is no overload in a gas engine. It is quite true that the economical load is up to the maximum load, but then in the ordinary way with the gas engine, as in the case of any other engine, you would not always work it up to the maximum load of which it is capable, and you would have a certain overload capacity in the gas engine in the same way that you have in a steam engine. There is one other small point which occurred to me, and that was in connection with the question referred to by the authors, of starting up three-phase motors with a generator from rest. Until comparatively recently I certainly was not aware what a simple method this is of starting up a big plant. In connection with a large three-phase power plant, we wished to run a couple of large 100 H.P. motors off the lighting set, a 375 k.w. steam turbine three-phase alternator. The full load current of each motor was 130 amperes, and when starting a motor up on to a line of heavy shafting by means of an auto-converter (the rotors were squirrel

cage), the current taken ran up to 400–500 amperes, and the voltage was knocked right down. I then tried fully exciting the generator, and starting up slowly from rest, with the result that directly the generator began to turn round, at the first movement, the current rose immediately to a little over 100 amperes, and then almost instantly dropped back to about 65, and did not exceed that until the motor got away and a full load was put on. That method has invariably been adopted since; we always start up the generator and several large 100 H.P. motors from rest in that way, the current in every case being less than the full running current of the motors. Mr. Dykes.

Mr. W. GEIPEL: I think the paper we are discussing to-night has been brought before us at an opportune moment. It is exactly ten years ago since Col. Crompton read his memorable paper on the costs of electricity supply, in which he showed us that a unit could be generated at the then astounding figure of 3d. In connection with that paper of Col. Crompton's, the principal points under discussion were the effect of the capital charges and the coal bill. The authors in their paper on p. 700 say that capital costs were minor considerations in the early days. I cannot agree with that, for I have been connected with central station work for something like twenty-three or twenty-four years, and it has always been a difficulty to reduce the capital cost to such an extent that it could compete with the cheap gas in this country. It was a difficulty which was not so exaggerated on the Continent or in America, because they had dear gas, but in England that has always been the difficulty. Col. Crompton in his paper showed us how to generate electricity at 3d. a unit, and he took rather a forlorn hope of the possibility of ever reducing the figure below 3d. on account of the capital charges. To show that this question of capital charges is one that was engaging the attention of engineers before then and after, I should like to read one or two words which I contributed to that discussion, although I am only one of those who emphasised this point. The late Prof. Hopkinson, Prof. Kennedy, Arthur Wright, and a host of others much more able than I am, also pointed out continually the importance of that very question. I said "The reduction of the cost of electricity supply stations was very largely indeed the business of us engineers. In my opinion the present high prices of electric supply are due mostly to an insufficient consideration having been given to this question of first cost. It is certainly not always judicious to incur every possible expenditure in providing for the saving in coal, labour, and stores, without regard to the consideration of outlay. For example, costly chimneys are frequently erected when less outlay in this respect would suffice, or condensers and economisers are erected capable of dealing with the maximum load, the consequence being that a large portion is utilised during only a mere fraction of the year. Mr. Geipel.

With regard to the curves which the authors give on p. 699, showing the cost of coal and various other items of working expenses and capital charges, in the discussion of Col. Crompton's paper I ventured to give what I thought might be taken as ideal costs against Col. Crompton's. Although 3d. was a marvellously low charge in those days, and not to be thought of almost because it was quite ideal, yet I showed that the

Mr. Geipel. cost might quite well come down to 2d. with an ordinary lighting load factor. I made my costs up in this way—and while I am reading these few items I would like to take the authors' figures and compare them with them. Coal was 1·5d.; the authors' is 1·5: water 0·01; the authors' 0·01: stores—I include all stores—0·04; the authors' figure is 0·01, but that only includes oil, so that I think it is fairly close: wages and repairs 0·2d.; the authors' 0·076; maintenance and profit 0·98 against the authors' 1·1, the authors' 1·1 being the equivalent of a 15 per cent. load factor, which was the basis upon which I worked the costs out in those days. In the end, my costs came out to 2d. per unit for the whole of the expenses, including distribution, whereas I take it that the authors' charges as shown on that page are exclusive of the distribution plant. I might also mention perhaps a more interesting way of showing

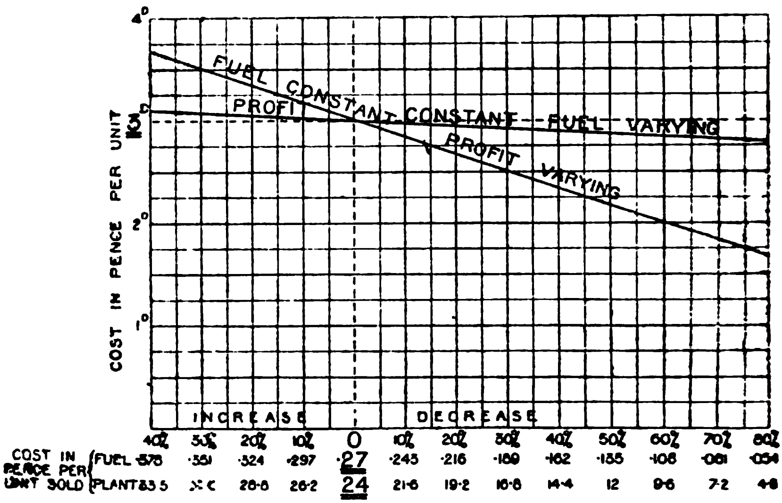


FIG. L.

the effect of the capital charges, instead of drawing curves for every load factor and every price per kilowatt, namely, by including the two together in one item and calling the capital cost so much per unit of output. I do not know whether that is clear, but in the Proceedings I gave a curve on this basis, which shows the effect of reducing this capital cost per unit output, as well as the equivalent saving in coal, and I would ask the President to allow the curve to be placed in the Proceedings. It works out to this, that if you decrease the cost of coal by 80 per cent. you make a saving of only ¼d. on Col. Crompton's then ideal cost, whereas if you make a saving of 80 per cent. on the capital cost you make a saving of 2d. per unit as the result.

On p. 702 the authors have suggested that in considering this question of increasing the capital outlay with a view to saving labour and so forth, no plant should be put in without allowing 15 per cent. on the actual cost plus repairs, although on p. 699 they put the figure at 10 per

cent. I would suggest that 10 per cent. is a very much fairer figure, although the money market at the present moment is bad; yet I think 10 per cent., even at present, is ample to cover standing charges for improvements. Mr. Geipel.

The President has asked us not to discuss turbines. I would only like to point out this one thing, that amongst the advantages which they specify the authors have omitted an important one from the engineering point of view, namely, the fact that the feed-water has no oil in it. I quite agree with what the authors say on p. 713, where I read, "In order to secure the shortest possible steam pipe, it is imperative that the boilers should be located directly opposite the engines they normally supply;" but when I turn to page 711, and look at the plans of the Carville station, which form the basis more or less of this paper, I see that the boilers are arranged in such a way that the steam pipes are about as long as they possibly can be. I think the authors would have been able to arrange for much shorter steam pipes if they adopted the system which they advocate on p. 713, that is, the division of the boilers and engines into sections, so that each section is independent of the remainder. In the plan before you, you will see that the whole of the boilers are feeding into one common steam pipe. I do not myself see any difficulty, although the authors have mentioned it, of arranging the turbines in such a way that the boilers should be more or less opposite to their respective turbines. If you arrange the turbines at right angles to the boilers, then, owing to the very narrow width and great length of the turbine, it is true you get an arrangement which does not enable you to have each turbine opposite its own section of boiler, but if you arrange the turbine lengthwise instead of across, you will then more or less have the turbines opposite to their respective boilers, and you will further have a very much cheaper engine-room because of the smaller span, the less strength of building required for the smaller span, and the lightness of the travelling crane, and consequently the lightness of the scantling of the building. By that arrangement you not only reduce your steam pipes, but you also make some saving in capital charges. Then on p. 719 the authors recommend the use of the boilers, so that at the peak of the curve they as well as the plant generally should be forced. That is a practice that has been adopted for many years past in central stations, and is being adopted continually at the present day.

Then on p. 726, where the authors discuss the question of whether they should drive the auxiliaries electrically or by steam, they give certain reasons for using electricity, with which I entirely agree, but they have omitted what seems to be a very important reason—that is, the example which they would set to the customers whom they want to induce to give up the use of steam engines; they have set an example to them in using electrically-driven auxiliary plant, which certainly is not an advantage to be lost sight of.

On p. 738 the authors discuss the difficulties of time circuit-breakers. No doubt it is a great difficulty. One way I would suggest of overcoming that difficulty is to adopt the following practice, which I have no doubt has been repeatedly adopted before, but many may not

Mr. Geipel. have known it—that is, to have a time fuse for protecting the smaller excess currents due to local or small short-circuits which may not do serious damage to the main plant, and also a circuit-breaker with an extra excess which will go instantaneously. In that way you protect your small short-circuits with a time fuse, and you also protect an instantaneous rush of current, which the authors say with an ordinary time fuse would not result.

There is only one other point I wish to refer to, and I hope it will not be considered hypercritical, but the authors continually make use of the word "unit" in their paper. They speak of "British thermal units," "Board of Trade units," "units of plant," and numbers of other units. Some years ago it was quite a common thing to call a kilowatt a unit, to call a plant a unit, to call everything a unit. I think it is a retrograde step to go back to the word "unit" for describing sections of plant or sets of plant, as they are generally called nowadays. I would suggest that, as far as possible, the word "unit" in the electrical world should be confined to the kilowatt-hour.

Mr. Andrews. Mr. LEONARD ANDREWS: There are quite a number of points arising out of this interesting paper that I should like to speak upon, but I will confine my remarks to that section dealing with automatic circuit-breakers, to which the authors have drawn particular attention. I was interested to see in the paper a reference to a new reverse-current circuit-breaker that has been introduced by Messrs. Brown-Boveri. Some of you may remember that I showed a similar circuit-breaker in this room about six years ago. It is very gratifying to me to see that device being adopted by such a distinguished firm, but I think perhaps I ought to give some excuse for having abandoned it, as we did, some years ago. The authors have referred to certain difficulties in using circuit-breakers of this description for alternating currents. One of the difficulties mentioned is that it is very susceptible to a drop in pressure across the shunt winding. There is another difficulty, however, which they did not touch upon, which is also akin to a drop in pressure effect. It is that in nearly all alternating-current cut-outs the series-current acts inductively upon the shunt current and so produces an opposing E.M.F. in the shunt. That is a point that has not, I think, been generally recognised in dealing with reverse circuit-breakers for alternating current. One feels that a circuit-breaker which works satisfactorily on a direct-current circuit ought to work equally well on an alternating-current circuit, but there is the additional difficulty, which you do not get with direct currents, of getting a device that is not affected in that way. We have, however, found it possible to do so. Mr. Jenkin referred to the fact that it is quite possible to make direct-current circuit-breakers which will operate perfectly well with a very excessive drop in pressure—in fact, without any pressure at all. This is undoubtedly quite possible with direct currents, but with alternating currents it appears to be impossible to make a discriminating cut-out which will discriminate between a generating current and a motoring current at any load if you have no pressure at all. The only thing we can do is to design cut-outs so that they will work with as big a drop of pressure as possible. In the various cut-outs that we

Mr. Andrews.

have been experimenting upon during the past few years, we have made a practice of obtaining records of the pull that we get with a generating current and with a motor current under various pressures. We have plotted the results obtained in curves, and have used these curves to guide us in the design of cut-outs. As a result of these investigations we have succeeded in getting an alternating cut-out that will operate reliably on 25 per cent. of the normal pressure (*i.e.*, with a 75 per cent. drop); and I think for most purposes, at any rate across alternating-current generators, that is about as low as it is likely to drop. With direct-current circuits of course it may drop down practically to zero. If anything goes wrong with a direct-current generator, it very often means that the current will flash round the commutator, and you get a low-resistance short-circuit across the 'bus-bars; you obviously cannot then get any pressure on the 'bus-bars, even although the generators may be coupled in parallel with batteries. But with alternating-current generators that is not very likely to occur. I was very much interested to hear that during the fire on the switchboard at Bristol, although the station was being fed by generators a mile or two miles away, and the 'bus-bars were, to all intents and purposes, short-circuited by a very heavy arc, the pressure never fell below 60 per cent. in what was really the distributing station, and it did not drop below 75 per cent. at the generating station. That shows that in that case there would have been plenty of pressure to operate reverse-current circuit-breakers if these had been constructed to operate with any pressure exceeding 25 per cent. of normal. There are, however, positions in which the pressure may drop to even 10 per cent. or 5 per cent. of normal. I refer to the attempt to use reverse-current circuit-breakers at the distributing end of duplicate feeders. I am sorry to have to condemn that system, because it was originally my suggestion to use reverse-current circuit-breakers for isolating faulty feeders. But in this position the pressure is only maintained by the C^2R losses in the feeder between the distributing sub-station and the fault. If the fault occurs near the generating station, current to the fault has to go out to the distributing station and back again, the distributing station being about halfway along the line. There will then be an appreciable pressure at the distributing station, which will probably be sufficient to operate the cut-outs; but if a low-resistance fault occurs near the distributing centre, the pressure will drop practically to zero, and I think under these conditions it is impossible to get a reverse-current circuit-breaker that will operate reliably. I could describe a device for protecting duplicate feeders, but I will not take up the time of the meeting in doing so to-night. If I am not out of order, perhaps I might say that if anybody is interested in this question of reverse-current circuit-breakers for any purpose, I have fitted up in Messrs. Cowan's London office a number of different types of reverse-current circuit-breakers to show experimentally why they are liable to fail in practice. We have found that cut-outs which appeared from the results obtained in the test-room to be perfect have, under actual working conditions, proved defective, and in every case where that has occurred we have investigated the cause of it, and taken care to remove it.

Colonel Crompton.

Colonel R. E. CROMPTON, C.B.: Attention has been very kindly called by Mr. Geipel to certain prophecies made by me when I was a much younger man, and he has pointed out that they have been over-fulfilled. In this he is not quite correct. The fact of the matter is that in the 3d. per unit that I put down as an ideal cost in those days I included certain charges which then existed and always will exist in our great cities, such as that for municipal rates, which is now nearly equal to the coal bill; but even in those remote days I was aware that electricity could be produced, if the load factor were good enough, at a very low figure indeed. In fact, I then knew of certain electrolytic works where the total cost was three-tenths of a penny per unit.

I believe I discussed with Mr. Insull, who I am glad to see is present, the possibility of very cheap supply provided we could get a good load factor. The engineers of modern power schemes are in the fortunate position of having to design work on the basis of a load factor quite outside the possibilities that we lighting men ever hoped for. With these good load factors the coal and labour bill became the important factors, instead of, as in the past, being quite a minor factor.

I think it is fortunate for the gentlemen who have now to design power-stations that they have behind them the much more difficult experience of us engineers who designed for the poor load factors, and I think there is a little tendency on their part to undervalue the very difficult work of those who have really made the present power-stations possible. There are probably many men in the room who were compelled to design generating plant really out of their own heads instead of having before them, as is now the case, the countless illustrated articles on generating stations with which the pages of every technical journal are filled.

Turning to matters to which I personally have given considerable attention, I regret to say that the authors have not told us much on the question of the day, *i.e.*, the real pros and cons of plant driven by steam *versus* internal combustion engines. When I heard of the paper I had hoped that we should have had this matter fully discussed, but I regret to see that no comparison is attempted in a quantitative sense. I, and no doubt others like myself, who are engaged in laying out works on a large scale, are all asking ourselves the question of how far we are now justified in spending our clients' money on steam plant in view of the remarkable progress made by internal combustion engines during the last few years. I may say that my firm have already obtained good results from internal combustion driven plant, especially for small stations. The working cost has been low and the capital cost not too high. I am now putting down plant of this description for one of the smaller stations at Calcutta, and am also installing for the same company a large steam turbine plant, so that by watching the two I hope to have full information at no distant date. I think it is obvious that all of us will have to act in this manner and introduce the newer form of internal combustion engines alongside of our older friend the steam engine. Turning to the power-stations illustrated by the authors, I think in the light of our present knowledge he is right in sticking to steam and using it in turbines, but I cannot see why the men who have

Colonel Crompton.

done so much for the steam turbine cannot go a step further and put the gases produced by continuous explosions also through turbines. In this way great simplifications and great economy would appear to follow. Such a man as Parsons, who has done so much to the credit of English engineering by the plucky way in which he stuck to the steam turbine, is sure to do something with the gas turbine if this is a possibility.

On another point I am rather disappointed in the paper. The author has told us very little regarding his boiler plant, the arrangement of which is, after all, of supreme importance. He has shown boilers in plan and in section, but he has not told us whether these are to be set and managed in the usual way, or whether he has taken note of the recent improvements in boiler setting which have had such a powerful effect in reducing the coal bills of the best power-stations. He also tells us little or nothing as to the best means of burning cheap fuels, which is a matter of the highest importance in power-stations. Any man can arrange a boiler setting to burn Welsh coal and get good results; but it requires a good man to deal with cheap bituminous coal having 30 per cent. of ash in it, such as is the case in our power-stations at Calcutta. With the latter I am glad to say we are now dealing successfully, getting high evaporative results. The boilers shown by the author appear to be water-tube boilers. Water-tube boilers have, up to quite a recent date, never in the hands of electrical engineers given the satisfactory results that they were capable of, entirely owing to defective boiler setting. All central station engineers of experience know how much depends upon this and on the means adopted to prevent air leakages, which have such an important effect in diluting and consequently lowering the temperature of the products of combustion. The extreme porosity of modern brickwork setting, and how it is best dealt with by steel casing or other means, are not even touched upon. If you read through the very voluminous descriptions of modern power-stations in the technical journals, you see illustrations of boiler setting only fitted for the anthracite coals of America or for the best Welsh of this country.

Turning to another point, the almost universal introduction of superheating in which I personally took considerable part, the users have, as a rule, blindly followed the first attempts made by us, the pioneers, and never have apparently realised the requirements to make superheating a success. Power engineers do not seem to have read—or if they have read do not seem to have profited by—Professors Callendar and Nicolson's joint paper, read before the Institution of Civil Engineers in 1898, on the Law of Condensation of Steam, in which they pointed out how much of the losses hitherto supposed to have been due to cylinder condensation were really due to leakages past the sliding surfaces of the pistons and valves, and how much these leakages could be reduced by superheating. This point was hardly touched upon in an otherwise excellent paper read by Mr. Henry McLaren before the Institution of Mechanical Engineers last year.

Another point which the authors do not seem to have noticed, but seems likely to affect greatly the cost of the boiler plant in power-

Colonel Crompton.

stations, is that of thermal storage. For many years Mr. Druit Halpin has been pressing this matter on, but it is only recently that he has obtained results so astonishing that apparently new laws will have to be applied to the heating of the water in our boilers. Quite recently in one of our power-stations, boilers that would evaporate from 12,000 to 14,000 lbs. of water as a maximum when fed with feed-water at a temperature of 180°, were found to evaporate at the rate of 36,000 lbs. per hour if the boiler was fed from a thermal storage vessel containing water of its own temperature and pressure. This seems incredible to us who had hitherto believed that all that possibly could be stored would be the sensible heat in the water apart from the latent heat. The importance of this in a modern power-station will be seen, when it is considered that the cost of the boilers themselves is only a small part of the modern boiler plant, and that automatic stokers, coal conveyors, coal bunkers and other accessories, are necessary in order that cheap fuel may be handled satisfactorily and economically.

Before I sit down I must congratulate the author on his very excellent Diagram I, showing how the cost curves are affected by the load-factor. I have used a table, though not quite so conveniently arranged as his, for the same purpose. A copy of this diagram ought to be hung up in the board-room of every supply company, or in the committee-rooms of municipal authorities, as it brings so forcibly and clearly before every one the desirability of improving the load-factor by every possible means.

Mr. Booth.

Mr. W. H. BOOTH: I should like first to ask the authors of the paper exactly what they mean by saying, on page 698, that a power-station has the low efficiency of not more than 10 per cent. I should like next to point out the difference between a power-station for electric light purposes, and one for traction purposes. In an electric light station I do not think the load-factor comes to more than 12 per cent.; at the same time the load-factor of the running plant may be 100 per cent., so that there is a vast amount of difference between designing a power-station for lighting and one for traction purposes. With the ordinary peak of a lighting station, which is somewhat of a triangular shape, the lower portion of the peak would, so far as the boilers are concerned, be dealt with by means of a heavy class of boilers, either Lancashire or dry-back or water-tube. The higher portion of the peak may be dealt with by means of such a boiler as the Solignac with liquid fuel; the top of the peak is dealt with by means of accumulators. In a traction station the load cannot be treated in the same way. The mean power of a traction station is practically identical all day, and the same class of boilers is required all day. The authors have referred to the question of load-factors. So far as my experience has gone, the load-factor of the tramway station, taking the factor as F, is of the form log. $F = 0{\cdot}33$ (log. C + log. N) where $N =$ number of cars and C is a coefficient which I have found to vary from 10 to 12 over a wide variety of conditions. With a station running about 65 cars, the load-factor is somewhere about 44 per cent. Ordinarily such a load is run by compound engines. The ordinary cut-off in the compound engine is assumed to be one-third of the stroke, and the latest cut-off about $\frac{3}{4}$ of the stroke; so that

Mr. Booth.

the minimum expansion is $1\frac{1}{3}$: that is, it is $1\frac{1}{3}$ in the first cylinder, and four times in the two cylinders. Supposing, however, simple engines are used with the view, as the authors say, of reducing capital expenditure, the cut-off for the peak of the load may be as late as $\frac{3}{4}$ of the stroke, and the mean expansion may be about four times. It is then possible to carry the load over the peaks by means of engines cutting off very late, and they could be of only half to two-thirds the cylinder volume of the compound engine. I think a good deal of economy might be obtained in that way. There comes in the question of cylinder condensation. The cylinder condensation in the simple engine is much in excess of that of the compound engine, but that may be overcome by means of superheat, and it is of course proportionately reduced by the use of jacketted cylinders. The authors referred to the question of breakdown: they say electrical engineers have come to regard breakdowns as inevitable. I think it was that fear of breakdowns which led to such an enormous duplication of plant: steam pipes were duplicated and feed pipes were duplicated. It is far better to put in excellent materials to begin with than it is to put in a lot of cheap trash. The object of some engineers seems to be to provide that breakdowns *shall* occur, not to prevent breakdowns. Why cannot we use solid-drawn steam pipes if we are afraid of lap-welds, instead of going to the expense of the ring main, which ought to be avoided, unless it can be used with advantage because of some other circumstance? Welded pipes are, perhaps, doubtful above a certain diameter. Then the pipes ought to be rivetted. There is no reason why a steam-pipe should not be more reliable than a boiler; and if equal care were taken in the manufacture and putting up of steam pipes, far greater satisfaction would result from their use. With reference to the auxiliary plant in the shape of mechanical stokers, the authors seem to doubt the value of the mechanical stoker. I would like to point out that it has more than one function. One of the functions of the mechanical stoker is the preservation of the boiler, because it enables boilers to be run at a more even temperature, especially when of the Lancashire type. There is another point. When the doors are opened for repeated firing the flues and the superheater are cooled down, if it is a Lancashire boiler, and consequently stresses due to uneven expansion are produced. A further point is that, with boilers set as they are set in this country, it is essential to have mechanical stokers to prevent dense smoke; that is, they will not prevent smoke, but they will dribble out the smoke throughout ten hours in such a small quantity at any one moment that the smoke inspector will not take notice of it. If you do not have a mechanical stoker, you are very likely to make smoke and get constant fines. I am sorry to say that boilers in this country are not set as they ought to be. I think I know to what Col. Crompton refers. We have got a boiler setting from the Eastern States of North America, which is thoroughly bad, for the reason that the setting adopted in the Eastern States is intended for smokeless anthracite coal. If you read some of the publications that come from the Western States of America, you will see that they pay a great deal more attention to the burning of

Mr. Booth. bituminous fuel than we do in this country; and they take care to have room in which to burn their fuel and to preserve temperature. A great deal has been written lately by some of the Western engineers, which seems to show that so far as the burning of bituminous fuel is concerned, they give much better attention to the problem than we do here, where we set water-tube boilers exactly as they are set for anthracite coal in America. With regard to the gas engine, it seems to me that the gas engine will put the steam engine out of court unless steam engineers, or rather engineers in charge, take care to work on a sounder basis of design. If electrical engineers take such boilers as are given to them without considering their setting, and without considering other points, they will find themselves very much in a corner. In the wall diagram of Carville station, the boilers are put at right angles to the engine. I am sorry to say that that is a good design with which I was familiar more than thirty years ago. Unless you use Lancashire boilers and put superheaters at the back of the boiler, or employ separately fired superheaters with water-tube boilers, you will not get good results. Superheaters are of little use in water-tube boilers because there is not sufficient temperature in the space where alone they can be placed. Michael Longridge says that you must have a head of 400° F. in order to get good effects from the superheater, and you cannot get that except from the Lancashire boiler. In a station of the Carville design you can put your superheater, which should be separately fired, in between the boiler and engine-room, and you can pass the whole of the steam from those boilers by the most direct form of steam pipe to the engine-room through the superheater. The separately fired superheater also gives you the advantage that you can reheat the whole of your water to the temperature of the boiler. That is a point which I had intended to emphasise, but Col. Crompton has dealt with it so much better than I can; he has given the evaporative power of a boiler fed at full temperature at about three times the ordinary. I have talked very much to deaf ears during the last few months in attempting to show that by means of heating the feed-water up to the temperature of the boiler you could get a saving of 20 per cent., but nobody will believe that such a thing is possible. I am glad to have such a supporter as Col. Crompton; although he has a different apparatus in view, I think he has the same principle in mind. M. Normand, of the French Navy, pointed out the peculiar advantages of fully-heated feed some years ago. We can only recognise the facts, though so far they are not explained. Sufficient, however, to know the facts, for, by means of superheaters, in which the control of the superheat temperature is effected by an internal column of hot water, it is possible to heat up the whole of the feed-water for the boilers to the full temperature of evaporation and to reduce the number of boilers by probably 15 to 25 per cent. on this count alone. The question of superheating is almost invariably dealt with by electrical engineers on the basis of an after-thought, and the result is that capital cost is increased and inefficient superheaters are added to boilers calculated already on a liberal basis for wet steam production.

Mr. E. KILBURN SCOTT: One of the more important matters raised

Mr. Kilburn Scott.

by the authors is where they say that the office buildings and stores should be kept quite separate from the power-station. I have written on this very point: see *Journal Royal Inst. Brit. Arch.*, vol. xi., p. 347. Non-inflammability is the great thing to aim at; and if stores and offices are placed round the switchboard they are obviously in the worst possible position. Many stations in England are so built, but it is seldom seen on the Continent. I should like to explain an idea I have for a central station building, into which turbines built with a vertical spindle would fit very well. In very large stations, such as the one at Chelsea, the boilers are arranged in double rows on two floors,

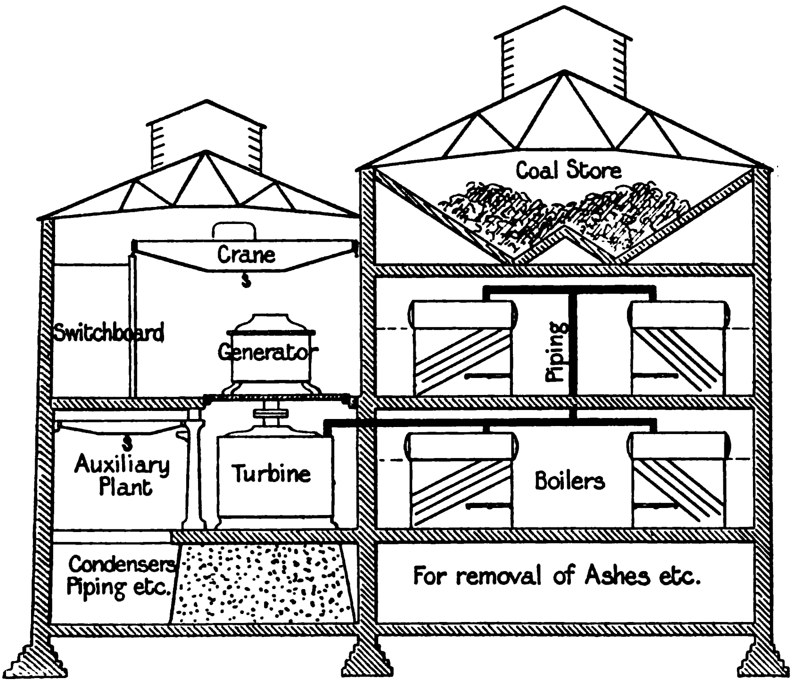


FIG. M.

and with the vertical spindle turbine it seems to me the engine-house might be built on two floors, the upper floor of the generator house being level with the upper boiler-house floor. In this way all the electrical apparatus could be cut off entirely from the steam apparatus; the generators and the switchboard being on the upper floor, and the turbine and its condensers, steam exhaust and other piping, and all the auxiliary plant down below. As shown in the figure, it could be well lighted by means of side windows.

Water-power stations, such as are much in use abroad, have not the danger that we have in England of steam and exhaust pipes bursting and shutting down the electric generators. An exhaust

Mr. Kilburn Scott. steam pipe in Manchester put out the whole of the lights of the city, and if an exhaust pipe can do that then a leakage from a live steam pipe may be much more dangerous. This is especially the case when generating direct at high voltage, say 11,000 volts, which is quite common, or as in Northern Italy at 16,000 volts. I believe Mr. Brown is ambitious of generating direct at even higher than that, I think therefore that my suggestion of putting all the steam apparatus entirely by itself is worthy of consideration; there would be two stairways connecting the two floors, and if necessity arose it would simply be a matter of a moment to throw down hatchways, and shut off the electrical plant entirely.

I may say that steam turbines are not the only prime movers that run on a vertical spindle; large slow-running steam engines are so arranged for dock pumping, for instance those by Easton's of Erith, at Southampton and Buenos Ayres. The design of thrust bearings is thoroughly well understood, thanks to marine practice, so it should not be difficult to build any size of engine with a vertical crankshaft. The reason I mention this is because in large slow-running gas engines the difficulty is to get an even turning moment. It will be remembered that the large steam engines now on order for the London County Council have combined horizontal and vertical cylinders, partly to get a short crank-shaft and partly to improve the turning moment. Now, with a vertical crank-shaft it would be possible to arrange the cylinders at an angle of 120 degrees, thus giving ideal turning.

The authors are quite frank in their objections to gas engines, but it appears to me that this question of power-station plant is not a matter of prime movers alone. It seems to me that the whole question is going to turn on the boilers, owing to the fact that about 1,000 horse-power is about the maximum size that boilers can be made. In the diagrams on the walls there is plenty of evidence of this; for example in the Carville station there are five boilers to one generating unit, and in the Commonwealth station eight boilers to one generator. The space occupied by the boilers and economisers, taking the one station with the other, is about four or five times the space occupied by the engine plant. Now this means a good deal of money not only in boiler plant but also in buildings, etc., and it is going to turn the whole question in favour of gas. After the present craze for steam turbines has had a run we shall have a period of gas engines, and eventually the gas turbine will make its appearance. Some work has already been done at Leeds on the gas turbine; it did not run long, but the fact that it ran at all is interesting. Mr. Reavell is an enthusiast in quick-speed steam engine work, and yet he is giving his attention to the development of the gas turbine (not the *steam* turbine). This, I think, shows the direction in which things are moving.

Mr. Steinitz. Mr. J. J. STEINITZ: Ten years ago we heard from Colonel Crompton that the necessity of keeping down capital cost was thoroughly appreciated and understood. This may have been so, but after the lapse, say, of five years, it was apparently entirely forgotten; in fact since this discussion was opened, I have met several engineers who are

responsible for some of the largest stations in the country, who told me that they had not till they read this paper thoroughly appreciated the immense importance of capital cost and the relation it bore to the selling price of the unit. If for nothing else, I think the authors are to be congratulated on emphasising this point. Economy of production has undoubtedly been fostered by the tables that are published week by week in the Electrical Press, and to those whose sole object has been to keep down "works costs" I think the results given by the authors on p. 701 with regard to the adoption of labour-saving devices are most pertinent. At one time the returns printed by the *Electrical Times* gave a figure representing in pounds the capital cost per kilowatt installed. This was always misleading, because mains were included, and the difference in the amount of mains engineers thought necessary to lay down made the figure quite useless. It is practically equally useless to consider the figures relating to the station unless some special basis is laid down, and the basis the authors have suggested is, I think, the right one. It has been my duty during the last year to read through a great many specifications by consulting engineers and others, and in those for engines and dynamos I think I may say in every case an overload has been called for. So long as this overload is to be given, irrespective of economical working conditions, the capital cost is little if any more than the capital cost of a smaller plant to give the same economical output as the maximum. It is perfectly justifiable, therefore, to use this overload as the authors suggest for peak loads in place of spare plant; and I think therefore for the purpose of calculating standby charges and for the general purposes of comparison, the authors have selected the right basis on which to rate a station. Last winter I went through a great many stations in this country. Some engineers wanted a certain amount of sympathy because they were running the station without any spare plant, but as a matter of fact if they had only considered the overload that each individual machine could give they would have found that they had really 20 to 25 per cent. of spare plant. I have come to the conclusion that very many of the engineers who have specified this overload do not take advantage of it. The authors' views will, I am quite sure, carry a very considerable amount of weight, and they will give engineers a very different opinion of the station capacity, and thus enable them to charge a lower price. There are only two points on which I am afraid I cannot quite agree with the authors. They mention £40 per kilowatt as being the charge for station plant and buildings. I looked through *Garcke's Manual*, and I find very few cases in which that figure has been reached. I can only suggest that if it has, then those gentlemen who have control of power companies, and who have a chance of selling current in competition with stations with a capital cost of £40, have a very good time before them. With regard to the arrangement of the auxiliary plant, I think the authors lay down a hard and fast rule that there should be no basement; but if you are dealing with a site on which you are able to start building right on the ground as it is, a basement forms itself naturally. I have known this to occur in one or two stations I designed; I found it exceedingly useful, and not at all expensive in working. In Mr. Steinitz.

Mr. Steinitz. conclusion, I should like to thank the authors very much indeed for their paper.

Mr. Madgen. Mr. Wm. L. Madgen: You have had a note of complaint from Col. Crompton as to what the paper did *not* contain, but I think it is only fair to the authors to point out that it already consists of forty-seven pages, and yet the matter is compressed to such an extent that, in common with other speakers, I am only able to deal with a very small portion of it. Mr. Geipel referred to the number of practical students in the economics of electrical supply who drew attention some years ago to the importance of the capital charges, as compared with the works costs, in the total cost of the unit. Doctor John Hopkinson, Col. Crompton, Mr. Arthur Wright, and others undoubtedly did so, but I do not think Mr. Geipel has perhaps remembered what has happened in the meantime. A very large number of stations have been put up by the municipalities, and the conditions under which they have been erected have not been conducive to economy in capital cost. Take one section alone, that of buildings; it is hardly to be expected that the borough surveyor architect, who desires to put you up a cross between a cathedral and a museum in which to burn your coal, is likely to give you very economical results in that department. I have had occasion from time to time to consider figures bearing upon these questions, and there is one comparison I have seldom seen made which is of very great interest. As many of you who are engaged in the manufacturing side of engineering are aware, it is sometimes represented as an axiom that you should turn over your capital once a year. In electric supply work, and perhaps in some other public services of that character, you do not turn your capital over in one year; in fact if you take an average of the representative electric lighting stations I think you will find that the ratio of gross revenue to capital expenditure is something like 12½ per cent., that is to say, you turn over your capital once in about eight years, and you have to pay your running expenses, interest, sinking fund, dividends, and all other charges out of that 12½ per cent. You will see the obvious importance of increasing the one factor and decreasing the other—decreasing the amount of the investment, and increasing the amount of revenue. The authors have dealt with the question of the economy of capital; in fact, I think we may fairly say that the keynote of the paper is the conservation of capital. The tables which have been so appreciatively referred to by other speakers, show that upon a 30 per cent. load factor the works costs are 0·25 per unit, and the capital costs are 0·275 per unit, making together 0·525 of a penny per unit. That figure, I think, affords some indication of the fate which is awaiting the small, separate generating stations, which I am glad to see are not now being erected with the same freedom as they were before the era of the large power supply undertakings. The authors have put before us in a very clear light the economic importance of the main power-station, and I think there is one serious aspect of it which we should bear in mind, namely, that it is not alone a question of what can be achieved by one main power-station, but also as to the improvement which can be effected in the result by diminishing the number

of generating stations. That is to say, if in a given area you can deal efficiently with the requirements of that area by means of one or two or three generating stations, then every additional station is an additional capital charge upon the community of that district. It is much to be regretted that the industry is still in an undecided frame of mind with regard to that point. In one district with which I have to do, namely, the North Metropolitan area, the District Council of Willesden has, upon the advice of Mr. Ruthven-Murray, merged their generating station into the North Metropolitan Power Supply scheme, and it has now become one of the main stations of that large area, with a much wider sphere of usefulness than it had before. On the other hand, in districts not far distant endeavours are being made to sever them from stations by which they are supplied, and additional generating stations are in view. That is, as I have indicated, a very retrograde step; but however unfortunate that may be, I think we may feel that the phenomenon of such a paper as this having been read by consulting engineers is a very happy omen. Mr. Madgen.

The PRESIDENT announced that the scrutineers reported the following candidates to have been duly elected:— The President.

Members.

Harry Fox.
Malcolm MacLaren.
Hans S. Meyer.
William Summerscales.

Associate Members.

Robert L. Acland.
Joseph W. Beauchamp.
Herbert Bell.
John H. Bowden.
Alexander G. Engholm.
Charles C. Metcalfe.
Edwin S. Reid.

Associates.

Walter E. Cooke.
William Kirkham.
Dr. William Martin.
Andrew M. J. Ogilvie.
Albert J. Smith.
William G. Smith, A.R.C.Sc.I.

Students.

Ernest W. Adams.
John C. Aston.
William Barrs.
James L. Bowers.
Arthur W. Brown.
L. G. Cooper.
Herbert S. Dransfield.
Harold Fasnacht.
William Fazackerley.
George N. S. Fitton.
John B. Foote.
James A. Forrest.
Charles J. Fox.
Herbert F. Gallaway.
William H. Gatley.
William Gillespie.
Gilbert E. Gledstone.
Douglas Gray.
Henry R. Greenyer.
Julius Gregory.
William Guildford.
Nigel E. Hall.
Christopher Hargreaves.
Eric C. Haccius.
James R. Halliwell.
Ernest Hamer.
William Hanna.
George Harlow.

Students (cont.)

Henry M. Harrison.
N. Hart.
Wilfrid Hartley.
Arthur Hawes.
Fred Heapy.
Edward P. Hill.
James N. Hindle.
Edo. J. Hitzen.
Robert Hodge.
Harold Hoggart.
Wilfred Holmes.
Arthur O. Holt.
George D. L. Horsburgh.
Harry Howarth.
Thomas I. Illingworth.
Charles W. Jackson.
Albert E. Jepson.
Alliston M. Johnson.
Harry Jones.
Jeffrey W. Jones.
Percy C. Jones.
Herbert Kay.
Roger K. Keer.
Richard Kendall.
Ronald S. R. Kneale.
William H. Lee.
Arthur O. T. Lemon.
Rupert C. Leslie.
Rowe C. M. Lewis.
John L. Lovell.
Harold Mackay.
Edwin J. McWilliams.
Harry V. Mahler.
Joseph W. Maitland.
Vernon Mellalieu.
Harold Marshall.
Roy C. Mather.
Percy T. Maybury.
Charles J. Melbourne.
John Mercer.
Fred Moore.
Claude E. Moorhouse.
Gordon Morris.
Frank Morton.
Edmund G. L. Mosley.
Gilbert Moss.
George I. Murray.
Thomas Nadin.
J. Edward Noake.
Arthur L. Ohlson.
William O'Keefe.
G. Ollongvist.
John A. Orme.
John Paterson.
Francis R. Pendergast.
John Harold Potts.
William D. Redfern.
Alfred E. Ricketts.
John Roberts, jun.
Alan W. Robinson.
James W. Ross-Jones.
Tom Rushworth.
David L. Sands.
Frank Shaw.
Robin M. Sheppard.
George M. Sime.
Sydney A. Skinner.
George Smith.
George E. Smith.
Gerring J. Smith.
Thomas W. J. Smith.
John A. Somerset.
Bertram E. Stott.
James Summers.
Herbert Taylor.
Peter Thomason.
Luther S. J. Thompson.
Ernest Thornley.
Harvey T. Thorp.
Harold Thorpe.
Evelyn T. Torbitt.
Thomas G. Travis.
M. Wandsworth.
Reginald W. Wainwright.
Bertram Walker.
Ernest Walker.
Frank G. Warburton.
J. Clapham Ward.
Samuel T. Webster.
William Weeds.
George Wm. Williamson.
Robert W. Willis.
Harry Wilson.
Walter D. Wilson.
Walter M. Winstanley.
Alfred Lee Wood.
Ernest Wooler.
Kenneth Younghusband.

The Four Hundred and Ninth Ordinary General Meeting of the Institution was held at the Society of Arts, John Street, Adelphi, on Thursday evening, May 12, 1904—Mr. Robert Kaye Gray, President, in the chair.

The President: Before proceeding with the usual business I have to inform you that Mr. Lloyd has to-day taken possession of the Secretarial chair. In doing this I feel it is only right, and it is certainly a great pleasure to me to state, that since the lamented death of Mr. McMillan, Mr. Rowell and Mr. Tree have carried on their duties in such a way as has I am sure been appreciated by all. You have probably noticed that during the interregnum we have been able to carry on our business in the ordinary manner, but I wish to make this public statement, as it often happens that those who do the work are not sufficiently recognised.

I have another announcement to make, namely, that at the Council Meeting to-day, in accordance with Article 17 of the Memorandum of Association, we elected an Honorary Member. We have on the two last occasions gone abroad to find persons qualified for this honour, but the Council this afternoon have thought they might come nearer home, and they have elected Major-General Webber, who is well known to you all as one of the founders of this Institution and an untiring worker wherever our interests are involved.

The minutes of the Ordinary General Meeting held on May 5, 1904, were, by permission of the meeting, taken as read, and signed by the President.

The names of new candidates for election into the Institution were taken as read, and it was ordered that they should be suspended in the Library.

The following transfers were published as having been approved by the Council:—

From the class of Foreign Members to that of Members—

Joseph Wetzler.

From the class of Associate Members to that of Members—

Herbert Reah Harper.

From the class of Associates to that of Associate Members—

Herbert William Miller. | William Dentson Perrott.
James Toulmin.

From the class of Students to that of Associate—

Harry Leonard Percy.

Messrs. A. E. Jackson and M. Wolfe were appointed scrutineers of the ballot for the election of new members.

Donations to the *Library* were announced as having been received since the last meeting from Messrs. Gauthier-Villars, Charles Bright, F.R.S.E., and E. & F. N. Spon ; and to the *Building Fund* from Messrs. B. Balaji and S. L. Brunton ; to all of whom the thanks of the meeting were duly accorded.

RESUMED DISCUSSION ON PAPER ON "POWER-STATION DESIGN,' BY C. H. MERZ, MEMBER, AND WILLIAM McLELLAN, ASSOC. MEMBER.

Mr. Venning.

Mr. A. VENNING : Without making any preliminary remarks, I may say that there are many points in connection with the paper on which I differ with the authors. In the first place I think too much attention cannot be paid to central station design as compared with the distribution system, the former being undoubtedly the mainspring of the entire system, which, if suddenly stopped, brings everything else to a standstill ; such, however, is not necessarily the case if an individual feeder or member of the distributing system gives out.

Referring to p. 697, the authors place "the cost of a boiler and high-speed reciprocating engine or turbine set at certain figures, and state that the total cost may run out at £40 per k.w., or even more." It is a well-known fact that small stations are far more expensive than large ones. As an illustration I will take the case of one with which the authors are familiar, comprising two small high-speed sets with a total capacity of 100 k.w. The building costs of that station alone amounted to £26 or £27 per k.w., and the plant cost at least £25 or £30 per k.w., the total thus exceeding £40 per k.w. On the other hand, taking a large station of 5,000 k.w. total capacity, consisting of a number of slow-speed engines, I find on reckoning up the plant, including engines, boilers, piping, condensers, and in fact everything, that the plant itself will cost only £18 per k.w., and the buildings £5 to £6 per k.w. That cannot be considered an extravagant price for a station with slow-speed engines and a building on fairly good architectural lines with ordinary walls. Coming to the case of a turbine plant, you will find this is still cheaper. In the case of a station now being built in this country, the total cost of plant and buildings will run out at £14 or £15 per k.w., of which the buildings will cost £2 per k.w., and this I think is a minimum price. When drawing a comparison, one must understand the case in all its bearings must be considered.

Passing to p. 700, in speaking of the economy of production and reliability of supply, our attention is drawn to simplicity of design and other factors, but one very important point has been omitted, and that is organisation, which in the case of any station, however designed, is indispensable to good results.

With regard to steam pipes, a great diversity of opinion exists on this matter. We all naturally wish to get from the boiler to the engine or turbine by the shortest possible path, but I really think where we have a main header running parallel with the boilers it should be made in sections, but coupled together either directly or by an expansion

loop, provided with isolating valves. It is often found useful to pass steam from end to end of a header, so that a generating set at the extreme end of a station may be operated independently of an adjacent boiler, which generally works in conjunction with it, but may temporarily be out of service for repairs or cleaning. Mr. Venning.

On p. 702, we are informed that "it is possible in laying out a station to avoid placing chimneys, flues, offices, and elaborately brick ends so as to interfere with extensions." On this point, the authors, whilst beholding a beam in someone's eye have forgotten the mote in their own, for if you only turn to p. 710, you will find in Fig. 3 that in their station at Neptune Bank they have placed a chimney and economiser at each end of the building, that being the very thing they wish us to avoid; there may be some special reason for this, which they will no doubt explain. In one case I note they have placed an economiser directly under a wall, which is not to be recommended, as it involves great difficulty in removing and replacing tubes, should such a course be necessary. Attention is also drawn to the mixture of plant often seen in stations, but although not specifically mentioned, they have in this same station four or five different types of prime movers, consisting of high-speed engines, three-crank slow-speed engines, four-crank slow-speed engines and a Parsons' turbine; surely there must be some special reason for this on which they will no doubt enlighten us.

Passing to p. 713, we come to the question of a steel frame structure and the "walls or filling in" between the columns. The steel structure is well adapted for large stations, but is rather costly for small plants. You may in certain localities propose the erection of a steel frame building with light brick walls, but on submitting your plans for approval, you find the borough engineer or surveyor has drawn up a set of building regulations for his particular district and can in no way depart therefrom, not even for his own buildings. An instance of that kind I experienced some time ago in the Midland Counties in connection with a Corporation tramway station. Concrete is also suggested, but I am quite sure it is decidedly more expensive than brickwork. After erecting the steel frame, the cost of providing and fixing a wooden casing, then mixing, placing and ramming the concrete, taking the casing down and finishing off the faces, must cost a great deal more than any brick wall. As to corrugated iron, I hardly think what I may term "a tin building" would be tolerated in many localities, certainly not in any residential district. One substance, however, to which attention might have been drawn is Uralite, because it is fireproof, a good non-conductor, weatherproof, cheap and attractive to the eye.

With regard to the right-angled type of station which has been brought to our notice, there is nothing new in that arrangement. As far back as 1890 a station of 20,000 H.P. capacity was built at Albany Street, Boston, U.S.A., on this same plan, whilst in the same city another on the same principle was erected by the Edison Electric Co. Furthermore, in the Albany Street station the offices, stores and other buildings were built apart from the main generating station. It is simply a case of arranging the plant to meet all conditions and fit the site.

The authors have taken great exception to basements. First of all

Mr. Venning.

they tell us it originated on the Continent. That is not so, as James Watt introduced it when placing his condensing apparatus below the floor line in his earliest engines, and the same practice has been maintained in connection with the textile and other industries. Coming to central stations, in the early days, even in America, it was found to be far cheaper and better to excavate the site and construct a basement in preference to digging a number of pits for foundations, a long trench for the walls and timbering the same. Again, there is a distinct advantage with a basement as compared with trenches, wells or pits. Supposing your pipes alone are placed there, they are always in sight and easy of access, a leaky joint or other defect being quickly detected if a man only walks through, say, once a day; whereas when pipes are placed in trenches, as many of you doubtless know, leaks go undetected for all time, and the trench is often made a receptacle for all kinds of rubbish. There is no doubt that the placing of condensing plant in the basement of central stations, especially where surface condensers were used, originated from want of knowledge in connection with condensers and the principles of condensation, many engineers objecting to place the condenser above the floor line from fear of water collecting in the pipes and finding its way back to the cylinder, but, it now being well known that water re-evaporates under the influence of a vacuum, the condenser is often placed on the main floor. I think in other respects this should be so, as the condensing machinery is in sight, and is a valuable piece of apparatus deserving the same amount of care and attention as a main engine.

Turning to p. 718, I notice the arrangement of roofs is rather peculiar, there being eight or nine different sections with no less than five valleys. Any one who is cognisant with architectual work knows that valleys are a very expensive item in connection with roofs. By extending the slopes to meet the section containing the coal bunkers and railway line only one valley would have been required, which would have reduced the cost and at the same time improved the appearance of the building.

Referring to economisers, the main question is whether they economise or not. If coal only costs from 4s. 6d. to 6s. per ton, it certainly does not pay to instal them; but when the price of fuel is 15s. or more per ton, I think an economiser is a valuable adjunct to any plant. Too many tubes are often put in, not only increasing the cost but also reducing the draught very materially. A good and efficient arrangement is to instal steam-driven feed-pumps, the exhaust steam being utilised in conjunction with a feed-water heater placed in series with an economiser of, say, half the usual number of pipes; by this means you can heat the feed-water to an equal if not a greater temperature than is possible with a large economiser, and it also will be found cheaper, as the heater will cost less than the additional number of pipes with the necessary foundations and other accessories. Economisers not only reduce the draught, but necessitate a much higher and more expensive chimney.

The authors are mistaken in saying the American practice is to omit economisers. Thirty years ago economisers were first used in the

States, and one of the earliest installed in connection with an electrical plant was at Albany Street, Boston, consisting of 2,400 pipes, made by Lowcock, of Shrewsbury. Messrs. Green have now a large works in the States, and have recently furnished two very large installations of 8,000 and 10,000 pipes to New York power-houses. Feed-water heaters are used because the boiler feed-water is generally taken from the city mains, the temperature in winter being near the freezing-point, and on this account it would never do to pass such cold water into boilers or economisers, the destructive effects being too great. Mr. Venning.

With the President's permission, I should like to say a word on turbine foundations, it being a point of great interest to all station designers. They take up little room and have cheap foundations, but you will find a great difference when considering the space occupied and the consequent weight per square foot on the foundation. For instance, a vertical turbine occupies less floor space than one of the horizontal type; but, on the other hand, the weight per square foot is just double that of the latter. To give a comparison, a vertical turbine of 5,000 k.w. capacity requires an area of 220 square feet, with a weight of 0·81 ton per square foot; whereas in a 5,500 k.w. horizontal turbo set, such as that being installed by the Westinghouse Company at Lots Road, Chelsea, the floor space is 598 square feet, but the weight per square foot only 0·41 ton, or one-half that of the vertical type. With smaller sizes of horizontal turbines the weight averages about 0·23 ton per square foot, the vertical being fully double this figure. This is a point which should be noted, especially by those contemplating extensions, where floors have already been made of sufficient strength to carry a load of at least 500 lbs. per square foot.

Mr. W. H. PATCHELL: This is one of the most interesting papers we have had. You go through it page after page, and keep turning over pages expecting the authors to give you some facts; but, unfortunately, facts which are of use to us are absent. They write about the way we are to put down stations for a very low cost per kilowatt, but there are not two lines in the paper as to what the stations which we ought to put down, and which we presume they have put down, have actually cost, nor do we find what the running costs of such stations have been. I think when we get a paper from good practical men like the authors they should state such facts, and I hope they will do themselves justice in the reply to the discussion, and give us the figures, so that the paper does not stand unsupported and in the conditional mood. As regards the diagram, the authors put the coal at 6s. a ton. If you treble that figure you get about the average price of coal paid in London, and if you treble it the works costs are exactly doubled. Then with regard to buildings, I followed that part of the paper with much interest, and also what Mr. Venning told us. We are told to put up a steel structure with a corrugated skin over it. In London we are not permitted to do that; in fact, they do not even let us go as far as I should like to go. Some years ago I wanted to use corrugated iron to a certain extent, not in the wholesale way in which the authors recommend its use. I went to the London County Council, but they would not have it. They said, "A steel building is not a permanent structure, Mr. Patchell.

Mr. Patchell. and the station is to be a permanent building," and I wanted more than a temporary license. The Tower Bridge had not been long opened, and I asked them if that had been an oversight, as that was steel! What I wanted to do with corrugated iron was on the boiler-house side of the works. I gather from the advice the authors give us that we should have a corrugated roof and sides to our switchboard house. That I should hesitate to put up, although the switchboard itself were built in concrete! As to the foundations, it is not right to say that you must not have a basement. In stations which I have been responsible for, we had to dig out the foundations to get the proper strata upon which to plant our machinery, and it was then cheaper to form a basement than it would be to fill up again; we should have been obliged to fill up to get above the water level if we did not have a basement. The remarks on switch-gear are very interesting, and I hope the authors will tell us something of their practical experience in that connection, more particularly as regards excess and time relays. I am now looking for time relays. I had one sent to me the other day which I have been waiting many months for. My idea of a time relay was a relay which would operate the switch after an overload of definite duration. All that this time relay will do is to operate the main switch so many seconds after the overload, and although it was only momentary the time relay went on merrily. That is not a central station engineer's idea of a time relay; so that if the authors have something good in that direction, I hope they will let us have the information in their reply.

Mr. Leach Mr. H. L. Leach: It would be very interesting if the authors could give us some further information as to the annual output on which their curves in Fig. 1 are based, and also if they could say whether the figures refer to units generated or units sold. Do they refer to the results which they hope to obtain at the Carville power-station? I have shown on a diagram the works cost of several central stations based on figures obtained from the *Electrical Times* and Garcke's Manual, and as the efficiencies of distribution of some central stations differ considerably, the figures are worked out per unit generated in order to obtain a truer comparison of the costs of generation.

The Table shows that Messrs. Merz and McLellan's figures ar already being obtained or are closely approached in this country if t higher cost of coal and wages, etc. in different districts, and d allowance for the lower load-factors are taken into account. It w be seen that the Newcastle-on-Tyne Company, with a comparatively l load-factor of 13·88, has already reached 0·15 pence for coal, a 0·023 pence for oil, water and stores, which closely agrees with t figures given in the paper; and low engine-room costs have be obtained at Bradford, Edinburgh, Glasgow, Leeds, etc., having rega to the lower load-factors in these towns. Turning to stations in Lond where the cost of coal is more than twice as much as the autho estimate for fuel, it will be seen that in 1903 the City of London Comp were able to show the remarkably low figure of 0·374 pence for co with a load-factor as low as 12·26; whilst the City and South Lond Railway Company, working with a load-factor of 49·20, has been able

Mr. Leach.

Cost per Unit Generated in London and Provincial Electricity Works.

Year of Working.	Station.	Units Generated.	Per Unit Generated. Coal.	Oil, Water, and Stores.	Wages.	Repairs.	Works Costs. Engine-room Costs.	Interest and Depreciation at 10 per cent	Total Costs.	Load Factor.	Cost per Kilowatt.
			d.	d.	d.	d.	d.	d.	d.	Per Cent.	£
—	Merz & McLellan	—	·150	·020	·044	·036	·250	·275	·525	30·00	30
1902	Newcastle-on-Tyne Co. ...	† 7,345,786	·150	·023	·082	·105	·360	1·187	1·547	13·98	51
1902	Bradford Corporation ...	10,125,189	·234	·045	·072	·117	·468	·498	·966	20·93	33
1902–3	Brighton " ...	† 8,122,966	·603	·060	·187	·170	1·020	·704	1·724	17·38	43
1902–3	Edinburgh " ...	10,196,954	·246	·035	·070	·194	·545	·908	1·453	14·31	37
1902–3	Glasgow " ...	13,197,612	·226	·043	·122	·252	·643	·748	1·391	14·01	33
1902–3	Leeds " ...	† 5,931,533	·210	·023	·127	·105	·465	1·533	1·998	12·31	43
1902	Liverpool " ...	† 25,762,314	·333	·054	·135	·117	·639	·623	1·262	25·11	32
1903	City of London Co. ...	† 17,419,352	·374	·026	·161	·297	·858	—	—	12·26	—
1902	" " ...	† 17,676,786	·472	·040	·176	·304	·992	1·633	2·625	12·07	66
1902	St. James & Pall Mall Co. ...	7,338,971	·601	·064	·176	·185	1·026	1·079	2·105	17·69	61
1902	City & South London Rly....	* 3,781,087	·310	·046	·056	·028	·440	—	—	49·20	—

NOTE:—The figures for interest and depreciation and cost per kilowatt refer only to cost of land, buildings, machinery, and plant.

* For half-year ended June 30, 1902. See *Proceedings of the Institution of Electrical Engineers*, Vol. 33, "The City and South London Railway: Working Results of the Three-Wire System Applied to Traction, etc.," by P. V. McMahon.

† Calculated from units sold at following efficiencies of distribution:—Newcastle, 75 per cent.; Brighton, 85 per cent.; Leeds, 75 per cent.; Liverpool, 90 per cent. City of London, 1903, 85 per cent.; 1902, 80 per cent.

Mr. Leach. reduce the cost of coal to 0·310 pence per unit generated. The higher capital charges of some of the stations is no doubt due to the increased expenditure incurred in the replacing of original plants by larger units, to experimental and pioneer work, and to the expenses incidental to reconstruction of stations, etc. The high cost of land in some towns, and especially in London, considerably affects the financial results as shown in the table of figures. It seems therefore almost certain that with the experience now at the disposal of the designer of power-stations, the authors' estimates of works costs will be easily reached and in all probability even lower costs may reasonably be anticipated.

The question of steam-pipe intercommunication mentioned by Mr. Venning is a very important one, and I think very few central-station engineers would care to work on the system adopted at the Carville power-station. Whilst the duplication of steam pipes advocated by some engineers is quite unnecessary, it does certainly seem desirable to provide some means of intercommunication between the various sets of generating plant in case of breakdowns, especially when only five sets are installed and the spare plant capacity of the station is small as proposed by the authors. Reciprocating engines do not seem to have received sufficient consideration in this paper. Many of the stations in the Table on p. 781 employ reciprocating engines, and excellent results have been obtained in these works. On the other hand, I quite agree with the authors as to the advantages of using turbines under certain conditions, and no doubt in the matter of high superheating, which will come forward, turbines do offer some way out of the difficulties of lubrication. Great stress has been laid in the paper on the reliability of turbines, but they seem to be very sensitive to the presence of water in the steam. The stripping of the blades from this cause is not unknown; whilst in other cases the breakage of the blades does not appear to have always been satisfactorily accounted for. Another point which the authors do not seem to consider favourably is the use of machine-stokers. No doubt very good results can be obtained with hand-stoking under favourable circumstances; but in central-station work one has to rely on the human element and has to take average work, and therefore I think machine-stoking should give rather better results than the average hand-stoking. Further, it would seem almost necessary to employ machine-stoking in large power-stations in order to overcome the difficulty of the smoke nuisance, and their use would tend to prolong the life of the boilers.

The arrangement of the boiler-house at right-angles to the engine-room as proposed for the Carville station certainly offers many advantages for large power-stations, but would not prove economical for smaller stations. The design adopted by the authors for their switchboards is very good, and it eliminates the complication of cables, etc., which is far too often prevalent in many central stations and increases the fire risks. In conclusion, I think the paper has been most useful in drawing the attention of engineers to the possibility of simplicity in the design of their stations, and in showing the importance of reducing the capital expenditure and at the same time maintaining the highest efficiency in the generating plant in order to

secure the lowest costs of production, on which the life and commercial success of a power company must depend. Mr. Leach.

Mr. Kempster.

Mr. J. W. KEMPSTER (*communicated*): The writers of the paper are to be credited with attacking the problem of station design on advanced lines, and the paper is in many ways suggestive to those engaged on this work. A strong point is made of the necessity of keeping the initial outlay as low as possible. Whilst this is doubtless true in a sense, strictly speaking it is not so correct to state that the capital expenditure should be kept either high or low, as that with given conditions as to load-factor, cost of fuel, etc., there is a certain capital investment which will enable the unit to be produced at the least cost. With a high load-factor and coal at 15s. per ton, it is obvious that expenditure in plant, such as feed-heaters, etc., would be justifiable, which with low load-factor and cheap coal would be unremunerative. The power-station must further be considered as part of the whole system, and, unfortunately, a high-voltage three-phase station involves complicated sub-stations. The crux of the whole matter really is the figure at which a unit can be delivered without interruption to the consumers' side of the sub-stations, allowing for capitalisation charges and a fair margin of profit to the supply company. A few figures actually obtained in connection with the supply from Carville and Neptune Bank stations would form a useful appendix to the paper.

Every power-station, however well designed, remains a compromise between conflicting factors. The condensing plant with its auxiliaries in Fig. 8 is presumably as liable to break down as the generators, yet to save capital there is only one condensing set for two engines. It follows that either one or both condensers must work partially loaded or alternatively there are two idle generators, assuming one of them to be spare. Cross connections would slightly improve matters at the cost of simplification, and so on. With one condensing set per generator the capital outlay would be somewhat enhanced, though not materially; but reliability and, under certain conditions, economy of operation would be improved; so that when all is said and done, the question as to what is and what is not to be installed must still remain a matter for individual judgment.

Coming to the question of design, if the authors' premises are granted, *i.e.*, that under all circumstances for large powers the steam turbine is to-day the best prime mover, it is difficult not to concur with their main conclusions, though there is room for difference of opinion as to details. For example, it is cheaper to enclose a given area under one roof than under several. Yet, as a matter of convenience, detached buildings are advocated. Multiple boiler compartments are not *per se* advantageous or conducive to ease of supervision, yet the turbine seems to require this arrangement.

Whilst agreeing with the views expressed in the paper as to gas engines, coal-handling plants, stokers, and the paragraph headed "Electricity *versus* Steam for Auxiliaries," it is scarcely sound economics to place rotaries in the station unless the continuous output is insignificant. If the proportion of continuous approaches 50 per

Mr. Kempster.

cent. of the three-phase output, either separate c.c. generators or combined sets would be simpler and more economical, and as the authors frankly admit continuous-current turbine sets are unsatisfactory owing to commutator troubles, the logical solution would seem to be to employ another type of engine. The cost per kilowatt for rotaries works out considerably higher than £1 per kilowatt, apart from the switchgear, room occupied, additional attendance, and reduced efficiency, whilst reliability is lessened by another link in the chain.

When the engine- and boiler-rooms are back to back, a ring steam main is superfluous, but if, for exigencies of space, these are end-on, some duplication would seem advisable less on account of safety than because, as otherwise the one pipe would always be under pressure, joints can be remade, valves reground, etc., without overtime.

Pipes in trenches and auxiliaries in pits are undesirable, and there is much to be said in favour of an open basement, once granted that the appearance of the station is no object. But the cost of ladders, grating and platforms, etc., must not be overlooked. From Fig. 16 it would appear, however, that at the Carville station there is a partial-covered basement, with the addition of several tiers of side floors constituting the switchboard galleries, surely not an arrangement consonant with either low first cost or a minimum of attendance.

Mr. Hooghwinkel.

Mr. G. HOOGHWINKEL (*communicated*): There are one or two minor points upon which I do not quite agree with the authors of this paper. In most cases it is quite possible and desirable to have the repair-shops and stores adjacent to the power-station, as it saves much labour and time in transporting heavy machinery over an extensive system of rails, turntables, cranes, etc., instead of picking up the heavy parts by the overhead crane and depositing them on a truck running straight into the repair-shop. Even for fairly good-sized stations this arrangement could be arranged for without any risk of fire; of course these shops should form separate buildings. The Brimsdown station of the North Metropolitan Power Distribution Company, with the design of which I had to do, shows an arrangement of this kind. Another point is the arrangement of the boiler plant end-on, which necessitates the longest, and less satisfactory, arrangement of the steam pipes. This may be necessary where very large turbo units are used, but in a station where turbo units up to 2,000 k.w. are used it is a matter of choice. We are limited by the size of our steam boilers, and for every 1,000-k.w. capacity the best we can do is to have two watertube boilers for each turbo if the turbos are arranged with their condensers next to them. This will give a single row of boilers as shown in Fig. 8. With units up to 2,000 k.w., four boilers in a double row, as in Fig. 9, are quite suitable, and the steam-pipe arrangement is much more satisfactory than with the boiler-house end-on, although the length of the piping is about the same (saving of valves). The capacity of a station on the above general arrangement may, in my opinion, be put at 10,000 k.w. to 12,000 k.w. instead of 5,000 k.w. If the station starts with three 1,000 k.w. units, the boiler-house may be on a single row first, and the extensions with a double row of boilers, as was done at the Brimsdown station.

As regards the position of switchgear, especially the high-tension 'bus-bar switches, I am of opinion that these should *always* be kept outside the engine-room in a special switch-house adjacent to the engine-room. This principle was first applied by me in some stations of a smaller type which I had to design, viz., Weston-super-Mare, where the switchboard was placed between and flush with the main stanchions of the engine-room, an arrangement giving the additional advantage of less span for the latter, and therefore a material saving in first costs. This same principle was applied to the Brimsdown power-station. This switch-house should be in two or more stories, the basement being used as cable-room. The condition of having plenty of room for and round the switchgear seems, to my gratification, fully recognised by the authors. Mr. Hooghwinkel.

Then, as far as the pipework is concerned, I would remind the authors that (having regard to the end-on boiler-house) the weak spots in the steam mains carrying high-pressure superheated steam are the valves, as capital cost as well as the safety of supply is concerned, and every valve which can be cut out represents a saving and additional safety. I also advocate separately fixed superheaters between boilers and engine-room.

Mr. C. H. MERZ (*in reply*) said: Mr. President and gentlemen, I am sure we must in the first place express our appreciation of the kind interest which you have taken in our paper. This is the more gratifying because the paper, after all, consists chiefly of the compilation and discussion of principles, the correctness of which most engineers would be prepared to admit. These principles, however, while individually admitted, have perhaps not been collected together, analysed, and arranged in quite the form we have endeavoured to follow—at any rate not so far as a station of large capacity such as we have discussed is concerned. It is difficult for a manufacturer, or indeed for any engineer who has not had actually to consider the design of a whole station, to realise clearly the relative importance of the various components both from a commercial and a technical point of view. Needless to say, a manufacturer's opinion as to an individual piece of apparatus is of great value, but when it becomes a question of assembling apparatus in a station, other considerations than the cost or the degree of efficiency of a particular piece of apparatus naturally step in. For instance, it is of no interest to me to hear from one manufacturer that he can supply switchgear equally efficient and at half the price of that of another manufacturer, if, when I come to assemble that switchgear and put it into a sub-station or generating station, it results in my having to spend a great deal of extra capital on the buildings. For this reason we are particularly indebted to those engineers, Mr. Jenkin, Mr. Patchell, Mr. Steinitz, and Mr. Venning, who have actual experience of the design of large stations, and who have been good enough to give us their views and to criticise our paper. As we had hoped to make clear, it was not our obiect to discuss in detall the merits or demerits of different pieces of apparatus. If we had done this we should have trespassed on your time to an even greater extent than I fear we have already done; but we do regret that after attempting to emphasise the Mr. Merz

Mr. Merz. desirability of the complete unit system throughout the whole of our paper, our meaning should still have been so obscure that one speaker should recommend that this system might be adopted, and that we should put the boilers opposite the engines.

Colonel Crompton referred to our omission of the names of pioneers in central station design. Again I think we can only plead lack of space. I need not say that there are so many eminent names connected with the design of central stations in the past, it would be most difficult to make a suitable selection within reasonable limits. We certainly do not claim that we are pioneers in central station design in any direction. We have especially referred in our paper to the design of a station by Messrs. Sargent and Lundi, the eminent American engineers who designed Mr. Insull's new station at Chicago, and who have probably designed more central stations than any one, and they have adopted in all essential features the arrangements that we independently adopted for Carville. We cannot therefore, in any way, claim that we have originated anything new in central station design. One or two speakers have referred to the fact that boiler-houses at right angles to the engine-house were erected twenty or thirty years ago. This is quite beside the point. There is no merit at all in a boiler-house at right angles to the engine-house unless it secures certain advantages, and in many cases a boiler-house at right angles to the engine-house might result in very great disadvantages—just the disadvantages which we have shown for Chicago and Carville have been avoided by the adoption of a right-angled boiler-house.

I will endeavour to compress our reply as much as possible, though it is somewhat difficult, as the scope of the questions discussed has been very large indeed. We will, however, try to reply particularly to those points which are criticisms of the essential features that we have endeavoured to bring out in the paper, and not so much to the remarks on individual pieces of apparatus, which it was not the object of the paper to discuss. I will also treat of the various points not in the order of the speakers, but in the order of the sections of the paper as it is arranged.

First of all as to the cost curves. These were drawn to be sufficiently near for purposes of design—they have not been drawn to represent, in our opinion, ideal figures. That is to say, we mention certain figures for repairs, wages, water, oil, coal, etc.—these are not figures which we consider the lowest we shall approach on the Tyne. On the other hand, as Mr. Patchell very rightly pointed out, the coal figure is not one which it would be possible at present to approach in London, for the simple reason that coal is so much more expensive here. We have fixed on the particular figures given to show how the curve is drawn, and I think I may say without hesitation that we shall get considerably below these figures at Carville—in fact, we have already got below them in the comparatively old Neptune Bank station. The same remarks apply to the figure of £30 per k.w., which Mr. Leach has shown on the interesting diagram which he has put up this evening. I may mention, in passing, that below that figure of £30 he puts the figure of cost per k.w. for the Newcastle-on-Tyne Company,

Mr. Merz.

i.e., £51. Of course I need not say that in a company which has trebled its output during the last few years, as the Newcastle Company has, any published records, unless carefully analysed, are entirely misleading. The difference between costs and the difference between load-factors and the difference in the output at the beginning of the year and at the end of the year is so enormous as to limit materially the value of any published costs. Major-General Webber and other speakers have asked us to give the actual figures. Major-General Webber was good enough to allude to a figure of £20 per k.w. which I gave in evidence before a Parliamentary Committee two years ago. I do not think that, at the present moment, it is quite in the interests of the companies who have to negotiate with customers, and whose designs and figures we have used to some extent, nor is it entirely fair to the manufacturers, that we should give the actual cost per k.w. which we have obtained at Carville, but I will say this, that the figures are below that figure, while the running costs will be considerably under these figures. It may be that in the future some opportunity will present itself for putting actual figures forward, but I do not think that at the present moment we can quite well do so. Referring again to Fig. 1, we of course agree with Mr. Addenbrooke that the coal-line ought really to rise slightly as the load-factor is reduced. I have already explained that this chart was drawn with the idea of presenting a general view of the question, and not with the view of being theoretically accurate down to the last fraction of a penny. We were very much interested also in the various remarks as to the relative costs of gas engines and steam engines, and particularly those of Mr. Addenbrooke, who referred to the use of gas engines in the south of England. Of course we would not assert that under all conditions, and in all localities, steam is better than gas, but it is hardly necessary to say that in our opinion the former is at present certainly better in the case of a power-station located on the Tyne.

Mr. Jenkin has put before us some of the designs which Dr. Kennedy and he have adopted. It is very good of him to do so, as these are really the points which are of special interest to us in the discussion on this paper. I wish that other engineers who have large stations had criticised the paper on the same lines. The essential difference between these designs and the design of the stations at Carville and Chicago which we have put before you, is that in the former stations there are several generating units supplied from one steam main or one group of boilers, it may be by a single pipe or it may be by duplicate pipes—in which case of course we get a ring main. In the case of the design which we put before you, the essential point is that one large unit is adopted, and it is coupled to its own boilers, not that there should be a group of boilers feeding a group of engines. It certainly seems to us that in cases where you have to adopt smaller units, and where therefore several boilers have to feed several engines, that the advantages of a right-angle boiler-house are somewhat reduced. We agree with Mr. Steinitz and Mr. Patchell that basements come naturally in the design of some stations. We think that if that is the case, the basement should, unless it be a very deep one and is merely

Mr. Merz. there because the foundations are built up from a very low level, be left open, and only a gallery put round the turbine or the engines, as the case may be, and all the pipes and everything should be open to view, including also all the auxiliary plant. Mr. Venning here rather misses our point. He assumes that because we object to basements we like trenches. What we want to do away with is obviously both basements and trenches, and have everything absolutely open to view. Mr. Kilburn Scott talked of the two-storey boiler-house and engine-room, and he has been good enough to send me privately a sketch of what he advocates. We cannot say that such an arrangement appeals very much to us. He proposes to put a concrete floor between the steam part of a vertical turbine and the dynamo part, and entirely to separate the two, but the difficulty of not being able to get any overhead crane to all the steam machinery, which is the part which needs most repair, is so great that I do not think any engineer who had to run a station would adopt such a design.

Mr. Patchell. Mr. PATCHELL: I thought the point was that there were no repairs on turbines?

Mr. Merz. Mr. MERZ: I think, however perfect turbines become, they and their auxiliaries will always need an overhead crane, but I quite admit the point.

Mr. Kilburn Scott. Mr. KILBURN SCOTT: I think you will find that I have left a space all round the generator covered with iron plates, which can be removed so that the crane may lift right through the bottom floor.

Mr. Merz. Mr. MERZ: In that case it practically becomes a gallery round the turbine.

Mr. Kilburn Scott. Mr. KILBURN SCOTT: I don't agree with that at all.

Mr. Merz. Mr. MERZ: Then Mr. Venning and Mr. Patchell have criticised our suggestion that no money should be spent on bricks and mortar. I quite see that in certain cases the reputation of the engineer may depend more upon the external architecture of his building than upon the costs, but I would remind you that we especially put a limit on the scope of our paper by saying that it dealt essentially with a station for power supply—in other words, with the design of stations supplying large areas, and the whole requirements for power and lighting in those areas. One of the assumptions which it was fair to make was, therefore, that the station should be put outside a town where land is cheap—in short, that all the advantages of the so-called power scheme should be made use of. In such cases we certainly still think that the use of corrugated iron is not only the most economical, but lends itself to extensions and alterations in a way which bricks and mortar cannot possibly do.

In connection with the rating of plant, we entirely agree with the remarks of Mr. Steinitz, and we are therefore necessarily at variance with Mr. Dykes, who suggested that it was hardly correct to state that a steam engine had a greater overload capacity than a gas engine, in view of the fact that a gas engine need not be operated always up to its full load capacity. This is perhaps the prevalent view, and the ordinary way of making comparisons between the capital cost of gas engines and steam engines. It is obviously, we think, not the right

one, because if a steam generator can give 50 per cent. overload for two hours at very little increase of capital cost, no matter what its economy, that must be a very valuable feature in comparing the capital cost between the two machines, and it is an essentially valuable feature in the case we are considering, namely, the design of power-stations for power supply over wide areas. If we come to stations which have to supply loads of 100 per cent. load-factor the question is somewhat modified, but of course no power-supply scheme can hope to have such a load-factor. With ordinary load-factors the question of overload capacity has more influence upon the reduction of capital costs—which we have seen are at least half of the total cost of production—than any other feature. I think that section No. 3 of the paper—that on the rating of plant—is the section which has been the least remarked upon, whereas we consider it perhaps the most important. Mr. Jenkin called attention in this connection to the fact that he thought it was necessary always to have two spare units, one of which could be undergoing a regular overhaul, while the other could stand by as a reserve to the running engines. We must say that we hardly consider this necessary under the usual conditions of power supply, which are such that a station has not to operate up to its peak load for more than three months in the year, and during those three months for only two hours a day. We think that in a station which has to operate under those conditions the overload capacity of the machines is well able to take care of the sudden breakdown of a single unit, especially as in such a station it may be assumed that the plant is put into thorough working order before the heavy season comes round. Even, however, if it is necessary under certain conditions, as it no doubt is, to have two units spare, one for overhaul and the other as a stand-by, we do not even think it is wise to reduce the size of the units as much as is sometimes done. At first sight it would seem more economical in capital cost to provide two spare units out of a total of eight than to provide two out of a total of five, but a little calculation will show that this is not so. Take an ordinary station for power-supply purposes, supplying a maximum load of 3,000 kilowatts: in one case we put in eight units of 500 kilowatts, six of them giving the 3,000, and two spare; and in the other case we put in five units of 1,000-kilowatt capacity each, three of them giving 3,000 kilowatts, and again two spare. I am sure that in every case it will be found that the five 1,000-kilowatt units cost less to instal than the eight 500-kilowatt units. In annual cost the saving will be very great, especially with the steam turbine, because the saving in labour and repairs, and also the saving in coal by the adoption of large units, is very great. Mr. Jenkin also referred to the advisability of operating auxiliaries from the 'bus-bars, and not direct from the individual units. I should like to have gone into that matter further, because I think considerable economy in capital is possible by operating the auxiliaries direct from the unit they refer to as against the elaborate switchgear necessary for stationary transformers operated from the 'busbars, but I think there is hardly time to do so. With regard to switchgear, we quite appreciate the pioneer work of Mr. Andrews, and Mr. Merz.

Mr. Merz. needless to say we regret with him that it was impossible, when we, eighteen months ago, had to decide upon a type of switch to find an English manufacturer who could show us a switch capable of dealing with the loads with which we had to deal that had actually withstood tests. I do not know that we would have asked to see a switch which had been adopted on a large scale, but it was not possible to see even a model switch in a manufacturer's works. It seems to us that if manufacturers wish to meet the demand for large switches, it is not a very expensive thing to make, at any rate, one complete sample. To close contracts on the basis of a design and then have to criticise it and have the gear altered is almost impossible when time is an essential element, as is almost always the case. Mr. Jenkin referred to the desirability of operating switchgear mechanically instead of electrically. I would only remind him that in all cases of automatic overload release it is practically essential to trip the switches electrically, and I do not therefore see much objection to closing them also electrically. Mr. Patchell asked me to give some further information as to overload relays and reverse-current relays. I should like to talk for half an hour on this subject, but I fear it is impossible. I would only say this: I do not think at the present moment any combination of overload relay and reverse-current relay will satisfactorily protect a system against faults. It is impossible to get any overload relay or reverse-current relay operating at the two ends of a feeder, for instance, which under certain conditions will not come out when they are not wanted to, when some other relays should come out, and which will always come out when they are wanted to. I am therefore sorry to say that the only conclusion is that, at the present time, there is no relay on the market which will satisfy all requirements.

(*Communicated.*)—Although we endeavoured to cover, in the course of our reply to a very full discussion, all matters affecting the general principles of station design which we have endeavoured to bring forward, we find on reading through the proofs of the discussion that there are still wanting answers to various small points which were raised, but which have not perhaps special reference to the subject of the paper. As, therefore, we should like our reply to be as full as possible, we avail ourselves of this opportunity of supplementing our remarks.

Mr. Addenbrooke raised the question as to whether the cost curves shown (Fig. 1) include the management charges of the station in the works costs, and whether these works costs are based on "Units Output" or "Units Sold." The works costs indicated are based on actual results obtained on "Units Output" some two years ago, so that they must now be taken as purely hypothetical figures. Station management is, as a matter of fact, not included, the item "wages" covering only the salaries of the running staff from the station-shift engineers downwards. This being so it does not matter whether the costs given are based on "Units Output" or "Units Sold"; but in passing we may say that it seems to us to be correct in considering station statistics to always take "Units Output" as a basis for comparison, and not either "Units Generated" or "Units Sold."

In reply to Mr. Geipel as to the amount to be put aside for sinking fund, if he will refer to the context he will find that the 10 per cent. on p. 700 is applied to the *whole* of the power-station, including land and buildings, whereas the 15 per cent. on p. 702 has reference to a particular section of the plant, in fact to mechanical stokers which require comparatively frequent repair. Mr. Merz.

In reply to Mr. Booth, we had in view the *thermo-dynamic* efficiency in stating that the efficiency of a power-station is not more than 10 per cent.

Mr. Barker raised the question as to the meaning of the term "Calculated Steam" (Fig. 2). We fear he has read this to mean "Theoretically Calculated Steam," whereas it is really the total actual steam per hour divided by the mean load in kilowatts.

Mr. Barker went on to say that the curve hardly gives the best result obtainable in calculated steam per kilowatt-hour from the particular turbine under test, pointing out that if the steam curve be produced it eventually drops as low as 16 lbs. We, however, naturally confined ourselves to the actual results obtained, and as power-station engineers we are only interested in such results as are obtainable in commercial operation. It is entirely the manufacturer's care to provide a turbine which is not so much out of proportion to the alternator that the best results are not obtainable by the combination.

Mr. Barker also inquired as to the power used in obtaining condensing water at the Carville station. In reply, this is from 2 to 2½ per cent. of the total output for each generating set. He was also anxious to hear the results obtainable from the Curtis turbine. We would refer him to the discussion on Messrs. Parsons, Stoney and Martin's paper on "Steam Turbines," during which one of the writers had occasion to quote some figures recently obtained by us on a 500-k.w. machine at Cork.

Mr. Kempster calls attention, in his communicated remarks, to the use of one condenser for the two small units at Carville. There are two reasons why this was done in this particular case. First, by using one condenser for the two smaller units, each of which is half the size of one of the main units, all the condensers and air-pumps at present in the station are of the same size and interchangeable. Secondly, it is with comparatively small turbines an advantage to use one condenser for two units, as when one unit only is running the advantage of the large condenser in giving a better vacuum, which is so important in the case of the turbine, is got without increase of cost.

Mr. Lupton was anxious that we should fill in the balance-sheet given on p. 709 as to the relative merits of gas engines and steam turbines. We are afraid that to do this would not be a very light task, for the reason that so much depends upon the local conditions and so many assumptions would necessarily require to be made. In order to arrive at a conclusion under the various combinations which go to make up the local conditions—cost of coal, cost of labour, cost of land, cost of buildings—it would be necessary to go through the whole process of designing a station for gas engines and a station for steam turbines. The result we have arrived at is, we consider, the right one as applied

Mr. Merz. to any place where coal is conveniently obtainable and cheap. In writing our paper it was necessary, in order to discuss power-station design in detail, to settle on *some* type of generating unit, hence the time we devoted to the discussion of steam turbines. We can only repeat that for all ordinary power-station purposes in this country we would decide at present in favour of steam turbines—at the same time it will be remembered that we took special pains to limit our conclusion to the present state of engineering development.

Mr. Venning is very critical of Neptune Bank Power-station, and considers it as contrary to various recommendations made by ourselves in the paper. This is easily accounted for. Neptune Bank was designed five years ago and is working under entirely different conditions from those which it was originally intended to meet; that it has met the altered conditions satisfactorily is shown by the fact that it has a lower generating cost than any other station in the kingdom. We, however, would not for a moment hold it up as a type of station to be copied now. The site plan was not put into the paper for this object, but solely to show the arrangement of auxiliary buildings. We can mention other points in which Neptune Bank does not agree with our present ideas of design. For instance, the Neptune Bank station has large basements of which we expressly disapprove in our paper.

At the same time, some of the matters referred to by Mr. Venning can be explained. The two chimneys in their present position do not necessarily interfere with extension of the boiler-house, but even if they did it will be seen that it would not matter, as there is no room for extension on this particular site in any case. As soon as the companies on Tyneside were amalgamated it was decided to buy a larger and more convenient site, to finish this station and not to extend it any further. In the meantime, however, before Carville could be got under weigh Neptune Bank had to deal with a very much heavier load than was ever contemplated when it was first commenced. A station upon such a site would never have been commenced had these developments been foreseen. Again, with regard to the variety of prime-movers at Neptune Bank, one of the requirements which we laid down as an essential feature of correct design was that due consideration should be given to possible changes in the type of prime-mover. Thus, in this case, reciprocating engines were installed first, turbines being installed later after they had been developed in larger sizes.

Mr. Venning also referred to a very interesting point, namely, the question of dividing the roof up into a series of spans as against having one big span. Up to a certain size, of course, one span is cheaper than two or more, but above a certain size it will be found that it is much cheaper and more convenient to divide up the roof into narrower spans, especially if the arrangement of plant is such that these spans need not all be of the same height. In any case if heavy columns and elaborate bracing have to be erected to support the bunkers, it is obviously the cheapest possible arrangement to avail one's self of these columns to carry a roof span, and thus the multiple-span roof as against the single-span roof naturally results.

Colonel Crompton complained that several points in connection with

the raising of steam had not been dealt with. Such details, although of very great importance, are somewhat beyond the scope of this paper, though, as mentioned in the conclusion, had space permitted we should like to have devoted a section to the boiler-house equipment. We await Colonel Crompton's promised paper on the "Production of Steam" with great interest. Mr. Merz.

Several speakers have referred to arrangements of steam-piping in a more or less general way, but we think that no one has seriously contended our main point that the less steam-piping the better. Any one who has had experience in the design of a large station will appreciate that the steam-piping with the "End-on" boiler-house is reduced to a minimum, and we can only assume that those speakers who have questioned this point or referred to other arrangements, have not made themselves sufficiently acquainted with the design which has been adopted at Chicago and Carville.

Mr. Jenkin referred to the complete unit system of operating auxiliary machinery suggested by us at the end of Section 4 as a possible alternative to our recommendation, which was that the auxiliary machinery should be operated by means of induction-motors from the main 'bus-bars. We have not ourselves actually tried this method in practice, but we have recently worked it out for a station and have found a considerable saving in main switchgear. We have, I think, explained in our paper how and why this method might be made more reliable than operation from the main 'bus-bars, besides saving capital expenditure due to there being no necessity for additional main switchgear panels for the static transformers.

Mr. Venning referred to the staff organisation in the running of a power-station, and while this is obviously very important it is again a point which is beyond the scope of our paper.

We wish to say, in conclusion, that we are in cordial agreement with the remarks of Mr. Steinitz and Mr. Madgen as to the overpowering importance of low capital cost. In our opinion, reliability of operation and reasonable economy having been secured, this more than anything else is the criterion of success in power-station design. Mr. Madgen's reference to the relation of revenue to capital, and the "conservation" of capital, are worthy of the most careful consideration, if electric-power undertakings in this country are to be the success we all hope they will prove to be.

The PRESIDENT: Although it is hardly necessary to ask you to give your thanks to Mr. Merz and to Mr. McLellan, as the discussion their paper has given rise to is the best proof of its value and of your appreciation, yet I propose that we accord them a hearty recognition of their labours. The President.

The vote of thanks was carried with acclamation.

The CHAIRMAN: I have now to ask the Hon. C. A. Parsons, Mr. Stoney, and Mr. Martin to read their paper. The Chairman.

The following paper was then read:—

THE STEAM TURBINE AS APPLIED TO ELECTRICAL ENGINEERING.

By the Hon. CHARLES A. PARSONS, F.R.S.; G. GERALD STONEY, and C. P. MARTIN (Members).

In the early days of electric lighting the speed of dynamos was far above that of the engines which drove them, and therefore belts and other forms of gearing had to be resorted to. To make a high-speed engine, therefore, was of considerable importance, and this led to the possibilities of the steam turbine being considered. It was, however, at once seen that the speed of any single turbine wheel driven by steam would be excessive without gearing, and in order to obtain direct driving it was necessary to adopt the compound form, in which there were a number of turbines in series, and thus, the steam being expanded by small increments, the velocity of rotation was reduced down to moderate limits. Even then, for the small sizes of dynamos at that time in use, the speed of revolutions was high, and therefore a special dynamo had to be designed. Speaking generally, an increase of speed of a dynamo increases its output, and therefore it was obvious that such a high speed dynamo would be very economical of material.

These considerations led in 1884 to the first compound steam turbine being constructed. It was of about 10 horse-power and ran at 18,000 revolutions per minute, the diameter of the armature being about three inches. This machine, which worked quite satisfactorily for some years, is now in the South Kensington Museum.

Before, however, this first turbo dynamo was constructed, a set of preliminary experiments were commenced at Gateshead-on-Tyne, with the view of ascertaining, by actual trial, the conditions of working equilibrium and steady motion of shafts and bearings at the very high speeds of rotation that appeared to be essential to the construction of an economical steam turbine of moderate size. Trial shafts were run in bearings of different descriptions up to speeds of 40,000 revolutions per minute; these shafts were 1½ in. in diameter and 2 ft. long, the bearings being about ⅜ in. diameter. No difficulty was experienced in attaining this immense speed, provided that the bearings were designed to have a certain small amount of "give" or elasticity, and after the trial of many devices to secure these conditions, it was found that elasticity combined with frictional resistance to transverse motion of the bearing bush, gave the best results, and tended to damp out vibrations in the revolving spindle. This result was achieved by a simple arrangement; the bearings in which the shaft revolved was a plain gun-metal bush with a collar at one end and a nut at the other; on this bush were threaded thin washers, each being alternately larger and smaller than its neighbour, the small series fitting the bush and the

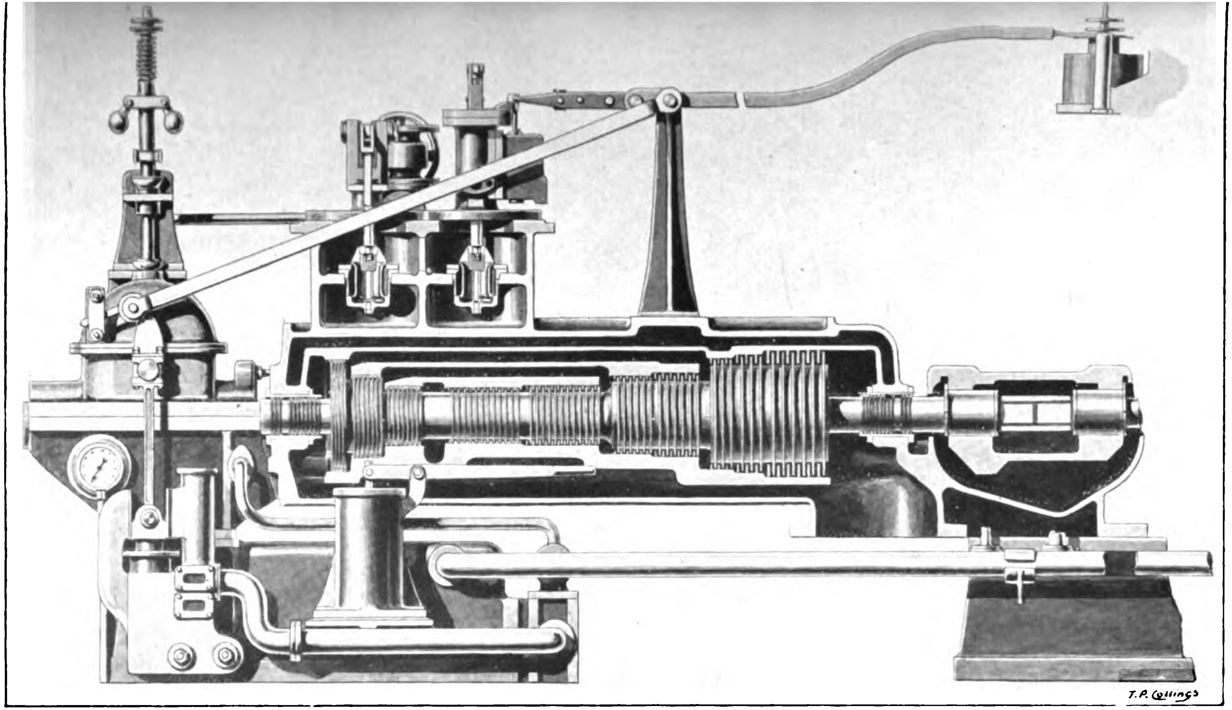


FIG. 1.—Sectional Elevation of Steam Turbine.

larger series fitting the hole in the bearing block, these washers occupying the greater part of the length of the bush. Lastly, a wide washer fitted both the bush and block, forming a fulcrum on which the bush rested, while a spiral spring between the washer and the nut on the bush pressed all the washers tightly against their neighbours. It will be seen now that, should the rotating shaft be slightly out of truth (which it is impossible to avoid in practice), the effect is to cause a slight lateral displacement of the bearing bush, which is resisted by the mutual sliding friction of each washer against its neighbour. The shaft itself being slightly elastic, tends to centre itself upon the fulcrum washer before mentioned; and under the gyrostatic forces brought into play by the rapid revolutions of the shaft and influenced by the frictional resistance of the washers, the shaft tends to assume a steady state of revolution about its principal axis, or the axis of the mass, without wobbling or vibration. This form of bearing was exclusively used for some years in turbine engines aggregating some thousands of horse-power, but it has since been replaced by a simpler form fulfilling the same functions. In this latter form the gun-metal bush is surrounded by several concentric tubes fitting easily within each other with a very slight lateral play; in the interstices between the tubes the oil enters, and its large viscosity when spread into thin films has the result of producing great frictional resistance to a rapid lateral displacement of the bearing bush; the oil film has also a centring action, and tends, under vibration, to assume a uniformity of thickness around the axis, thus centring the shaft, and, like a cushion, damping out vibrations arising from errors of balance. This form of bearing has been found to be very durable and quite satisfactory under all conditions.

These first turbine engines consisted of two groups of 15 successive turbine wheels, or rows of blades, on one drum or shaft within in a concentric case on the right and left of the steam inlet, the moving blades or vanes being in circumferential rows projecting outwardly from the shaft and nearly touching the case, and the fixed or guide blades being similarly formed and projecting inwardly from the case and nearly touching the shaft. A series of turbine wheels on one shaft were thus constituted, and each one complete in itself is like a parallel flow water turbine; the steam, after performing its work in each turbine, passing on to the next, and preserving its longitudinal velocity without shock, gradually falling in pressure as it passes through each row of blades, and gradually expanding. Each successive row of blades was slightly larger in passage way than the preceding to allow for the increasing bulk of the elastic steam, and thus its velocity of flow was regulated so as to operate with the greatest degree of efficiency on each turbine of the series. All end pressure from the steam was balanced by the two equal series on each side of the inlet, and the revolving shaft lay on its bearings revolving freely without any impressed force except a steady torque, the aggregate of the multitude of minute forces of the steam on each blade. It constituted an ideal rotary engine, but it had limitations. The comparatively high speed of rotation that was necessary for so small a size of engine as this first example made it difficult to prevent a certain spring or

whipping of the shaft, so that considerable clearances were found necessary, and leakage and loss of efficiency resulted. It was, however, perceived that these defects would decrease as the size of the engine was increased, with a corresponding reduction of rotational velocity, and consequently efforts were made towards the construction of engines of larger size, which resulted in 1888 in several turbo alternators of 120 horse-power being supplied for the generation of current in electric lighting stations, and at this period the total horse-power of turbines at work reached in the aggregate about 4,000, all of which were of the parallel flow type and non-condensing.

About 1890, however, on account of the temporary loss of control of the patents, the radial flow type of turbine was reluctantly adopted, and this was in 1892 arranged to work condensing, and a 100 k.w. plant driving a 2,000 volt. single-phase alternator at 80 periods, which ran at 4,800 revolutions per minute and therefore was two-pole, when tested by Professor Ewing was found to take only 27 lbs. per kilowatt-hour

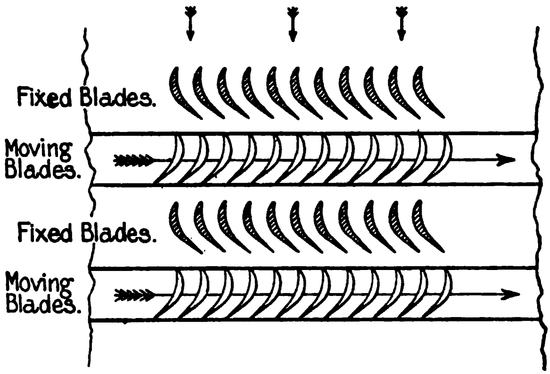


FIG. 2.—Arrangement of Blades.

with 100 lbs. steam pressure moderately superheated to about 70° F. and with 27 in. vacuum, a result comparable with the best obtained by reciprocating engines at that time, and thus a wide field was opened up for the use of the steam turbine as a prime mover. Many of these plants, mostly of 150 k.w., were made for the electric lighting stations of Newcastle, Cambridge, Scarborough, and elsewhere. In 1894, on the recovery of the original patents, the parallel flow type was reverted to, with considerable improvements in design calculated both to increase the economy and decrease the cost of manufacture. Instead of the steam entering at the centre and expanding both ways, one set of blades was replaced by a set of dummy pistons which were substituted for them, in which a grooved piston or dummy on the spindle ran close to but not in contact with corresponding grooves in the cylinder, thus making a practically steam-tight and yet frictionless joint. The bearings also were made of the later type, with several concentric tubes. At the

same time the system of blading was greatly improved, giving a more perfect form of blade, and one also with much greater mechanical strength than in the original formation. A section of this type of turbine is shown in Fig. 1, and a diagram of the blades in Fig. 2. The first large turbines of this improved type were of 350 k.w. output, and were placed in the Manchester Square station of the Metropolitan Electric Supply Co., this station being threatened at the time with an injunction for vibration caused by the reciprocating engines used there, and the substitution of the turbines proved entirely satisfactory to the Company.

In 1900, two 1,000 k.w. turbo alternators were supplied to the City of Elberfeld in Germany, and when tested by a committee of German experts on behalf of the city, the following results shown in Table I. were obtained :—

TABLE I.

Load.	Temperature of steam C°	Abs. steam pressure. Before Stop Valve 2. Kg. per cm.	Abs. steam pressure. Outlet L.P. Cm. of Hg.	Average load. K.W.	Steam per K.W.-hour. Lb.	Steam per K.W.-hour. Kgs.	Revs.
Preliminary Test (overload)	230	10·10	4·13	1172·7	18·22	8·25	1493
Normal	192	10·47	3·9	994·8	20·15	9·14	1461
Overload	189·5	10·11	4·65	1190·1	19·43	8·81	1486·6
¾ load	190	10·76	4·0	745·35	22·31	10·12	1469·9
½ load	209·7	10·40	3·4	498·7	25·2	11·42	1473
¼ load	196·4	10·14	3·7	246·5	33·76	15·31	1485
No load with excitation... ...	193	10·34	3·2	—	lb. p. hr. 4,065	—	1488·3
No load without excitation ...	194·5	10·49	2·68	—	2,067	—	1504·5

These turbines were of the tandem type in which the expansion of the steam was first carried out in a high-pressure cylinder and completed in a low-pressure, but it was soon found that better economy, except possibly in very large sizes, could be obtained by having the whole turbine in one cylinder.

Large numbers of tests have been made from time to time, chiefly by various consulting engineers and station engineers, out of which the following are selected, as shown in Table II. :—

TABLE II.

At Stop Valve.					Steam Used per Hour.	
Pressure above atmosphere. Lbs. p. sq. in.	Superheat. F°.	Vacuum. Inches.	Speed. Revs. per minute.	Load in K.W.	Pounds.	Pounds per K.W.
75 k.w. Continuous-Current Turbo for Banbury.						
141·2	84·2	27·1	4,140	75·7	2,006	26·4
144	0	27·0	4,140	75·2	2,201	29·2
142	0	27·1	4,140	56·6	1,777	31·2
135 k.w. Turbo Alternator—Findlay, Durham & Brodie.						
150·8	99·0	27·15	3,600	138·3	3,152	22·8
151·0	81·0	27·3	3,600	66·9	1,845	27·6
200 k.w. Continuous-Current Turbo for Shipley.						
150	57	27	3,000	204·2	4,538	22·23
151	55	27·9	3,000	101·2	2,698	26·67
156	181	27·3	3,000	202·5	4,130	20·39
151	166	28·0	3,000	100·27	2,446	24·41
375 k.w. Turbo Alternator for Dundee.						
152·9	—	27·4	3,000	376·9	8,143	21·6
149·4	148·9	27·5	3,000	374·06	7,202	19·25
350 k.w. Turbo Generator for Pennsylvania Salt Co.						
150	71·3	27·82	3,360	359·5	7,423	20·64
152	65·7	28·27	3,151	185·5	4,346	23·44
140·2	92·3	17·4	3,430	353·5	9,030	25·54
143·4	82·5	17·4	3,255	177·2	5,715	32·26
300 k.w. Turbo Alternator—Hulton Colliery.						
161·0	0	0	3,000	296·6	10,180	34·2
158·0	0	15·33	3,000	297·4	8,732	29·36
157·0	0	19·33	3,000	305·1	8,369	27·43
152·0	0	22·33	3,000	303·4	7,764	25·59
154·0	0	25·33	3,000	303·15	7,336	24·19
158·0	0	26·58	3,000	303·2	7,020	23·15
300 k.w. Turbo Alternator—De Beers Explosives Works.						
150·0	53·3	27·88	3,000	312·1	6·260	20·06
153·0	50·0	27·78	3,000	231·8	4·960	21·45
150·5	40·2	27·9	3,000	154·5	3,670	23·75

1,500 k.w. Turbo Alternator—Newcastle-on-Tyne E. S. Co.

196	76	27·45	1,200	1,442	25,962	18·0
197	84	27·35	1,200	1,015·5	20,124	19·8
196	76	27·95	1,200	714·0	15,288	21·4
199	77	28·35	1,200	360·5	9,114	25·2
200	68	28·45	1,200	—	2,948	—

After 16 months' use the following figures were obtained :—

203	92	26·11	1,210	1,823	32,431	17·7
207	66	26·46	1,208	1,513	27,582	18·23

1,500 k.w. Turbo Alternator for Sheffield Corporation.

With Vacuum Augmentor and including 450 lbs. steam per hour used by it. See page 805.

113·6	108·3	26·69	1,455	1,316·5	24,732	18·76
111·6	156·4	27·12	1,500	1,061·6	19,830	18·66
141	113	27·72	1,500	512·7	11,425	22·3
154	47·5	27·72	1,500	0	3,128	0

Without Vacuum Augmentor.

115·6	143	25·18	1,500	1,029·3	21,264	20·7
137	119	25·97	1,500	534·25	12,820	24·02
150·3	72·4	26·62	1,500	0	2,957·4	0

3,000 k.w. Parsons Turbo Alternator supplied to Frankfort by Messrs. Brown Boveri & Co.

138·5	235	27	1,350	2,993	44,200	14·74
170·5	187	27·5	1,350	2,518	38,300	15·59
142	120	27·2	1,350	2,600	41,200	15·8
139	114	27·2	1,350	2,600	41,400	15·9
168·5	184	27·9	1,350	1,945	30,800	15·84
146	120	27·6	1,350	2,000	32,600	16·3
137	101	27·4	1,350	1,442	25,400	17·6
142	30	29·3	1,350	0	4,700	excited
142	30	29·3	1,350	0	3,560	non-excited

In all the above tests the barometer is taken as 30 in.
Superheat in degrees Fahr. in all cases.

In non-condensing turbines the following may be selected :—

250 k.w. Continuous Current—Messrs. Guinness, Son & Co.

At Stop Valve.					Steam Used per Hour.	
Pressure above atmosphere. Lbs. p. sq. in.	Superheat. F°.	Back Pressure. Lbs. p. sq. in.	Speed. Revs. per minute.	Load in K.W.	Pounds.	Pounds per K.W.
144	0	0	3,047	251·55	9,510	37·80
142·6	0	6	3,047	255·82	10,584	41·38
138	0	11·1	3,055	253·15	11,194	44·15
143	0	11·0	3,115	125·45	7,475	59·58

500 k.w. Turbo Alternator—Metropolitan E. S. Co.

At Stop Valve.					Steam Used per Hour.	
Pressure above atmosphere. Lbs. p. sq. in.	Superheat F°.	Vacuum. Inches. Hg.	Speed. Revs. per minute.	Load in K.W.	Pounds.	Pounds per K.W.
142	0	0	1,800	506·2	16,903	33·39
147	0	15·67	1,800	509·06	14,800	29·07
144	0	18·57	1,800	514·9	14,591	28·33
145	0	20·67	1,800	512·2	13,945	27·22
146	0	22·57	1,800	509·85	13,714	26·89
154	0	0	1,800	0	3,552	—
151	0	26·1	1,800	0	1,560	—

The effect of varying vacua is shown in a condensing turbine in Figs. 3 and 4, which are the consumptions of the 300 k.w. for Hulton

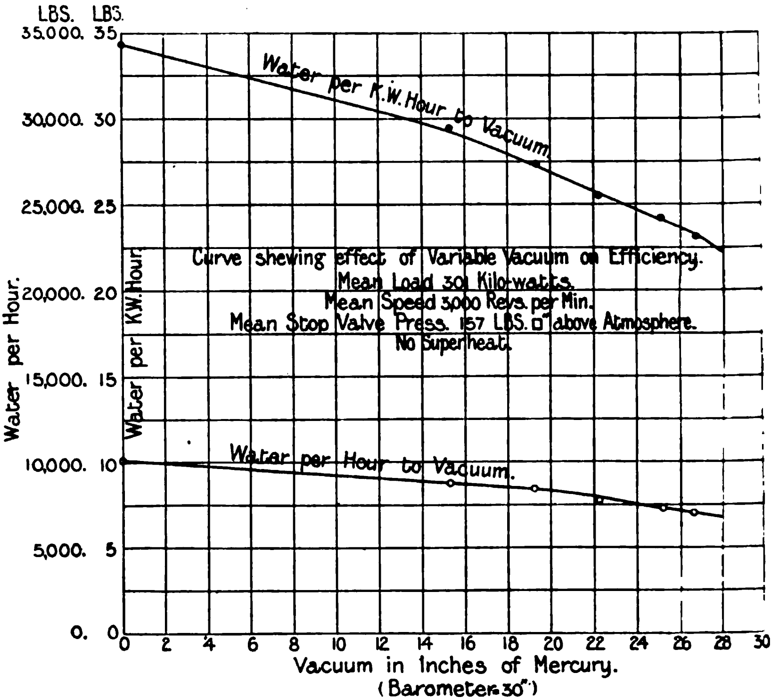


FIG. 3.—Hulton Colliery.

300 K.W. 3-phase alternator; 420 volts; consumptions at varying vacua.

Colliery, and in a non-condensing one in Fig. 5, which are those of one of the Metropolitan Company's 500 k.w. plants. The effect of varying load is shown in Figs. 6, 7, and 8 for the 1,500 k.w. plants for

the Newcastle Electric Supply Company and the Sheffield Corporation, which latter also shows the advantage gained by the use of the vacuum augmentor described on p. 805, and also for the Frankfort 3,000 k.w. turbine. In the case of the Newcastle Electric Supply Company's turbine, the consumptions in the latter half of the table were taken after 16 months' use.

It will be seen that under the conditions of, say, 140 lbs. steam pressure and 100° F. superheat and a vacuum of 27 in. (barometer 30 in.) the consumptions are in round numbers as follows:—A 100 k.w. plant

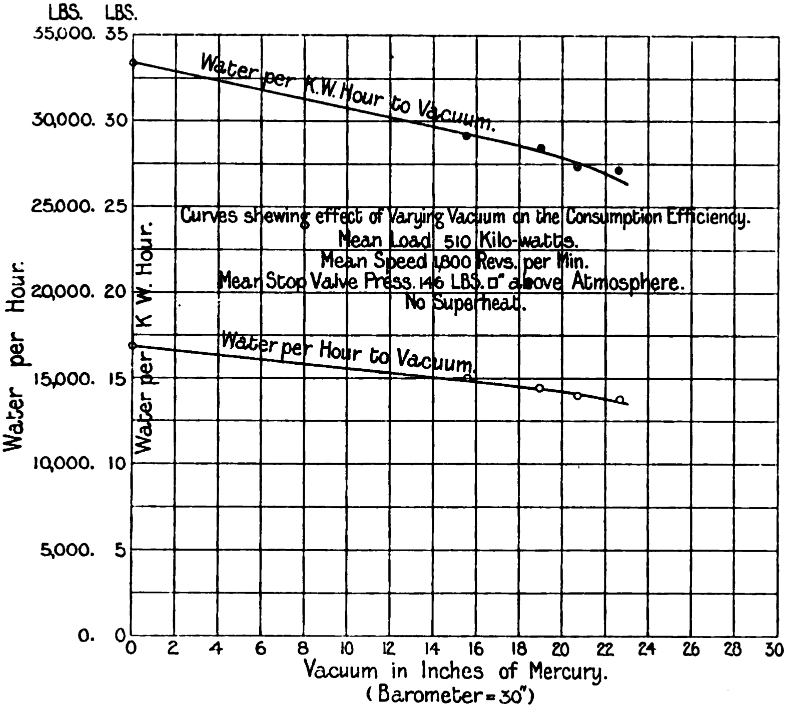


FIG. 4.—Metropolitan Electric Supply Co.

500 K.W.; 2 phase non-condensing turbo alternator; 1,000 volts; consumptions at varying vacua.

takes about 25 lbs. of steam per k.w.-hour at full load, a 200 k.w. takes 22 lbs., a 500 k.w. 20 lbs., a 1,000 k.w. 19 lbs., a 1,500 k.w. 18 lbs., and a 3,000 k.w. 16 lbs. These figures are derived from averages of a large number of tests which have been made from time to time. Without superheat the consumptions are about 10 per cent. more, and every 10° F. of superheat up to about 150° F. affects the consumption by about 1 per cent.

A good vacuum is of great importance in a turbine, as the expansion can be carried in the turbine right down to the vacuum of the condenser, a function which is practically impossible in the case of a

reciprocating engine, on account of the excessive size of the low-pressure cylinder and also of the ports, passages, and valves, which would be required. Thus in a turbine the benefit derived from a good vacuum is much more than in a reciprocating engine, every 1 in. of vacuum between 23 in. and 28 in. affecting the consumption on an average about 3 per cent. in a 100 k.w., 4 per cent. in a 500 k.w., and 5 per cent. in a 1,500 k.w., the effect being more at high vacua and less at low. It is thus seen how a good vacuum is of importance in a turbine plant, and in this regard it may be well to look into the conditions necessary

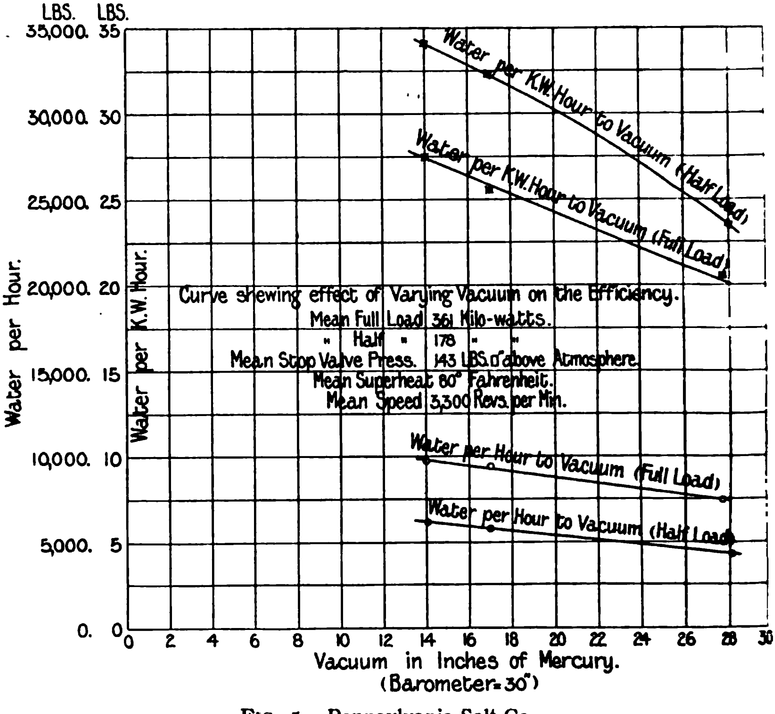


FIG. 5.—Pennsylvania Salt Co.

300 K.W. generator; 250 volts; consumptions at varying vacua at full and half load.

for obtaining the same. The first point is to avoid all air leaks, and this is easily accomplished in a turbine plant, as there are no packed glands and stuffing boxes to leak. The only places where leakage of air is possible are where the turbine spindle comes out of the cylinder, and here leakage of air is rendered very small by packing the glands with steam, so that any leakage which takes place is steam and not air. The next is to have a suitable condenser, and in this regard sufficient area must be allowed by suitable arrangements of the tubes, and also ample way for the steam between them, proper velocities of the water in in the tubes, sufficient supply of cooling water and efficient means of

cooling the condensed water so as to keep the air-pump cool, and full provision for extracting by the air-pump and other means the inevitable

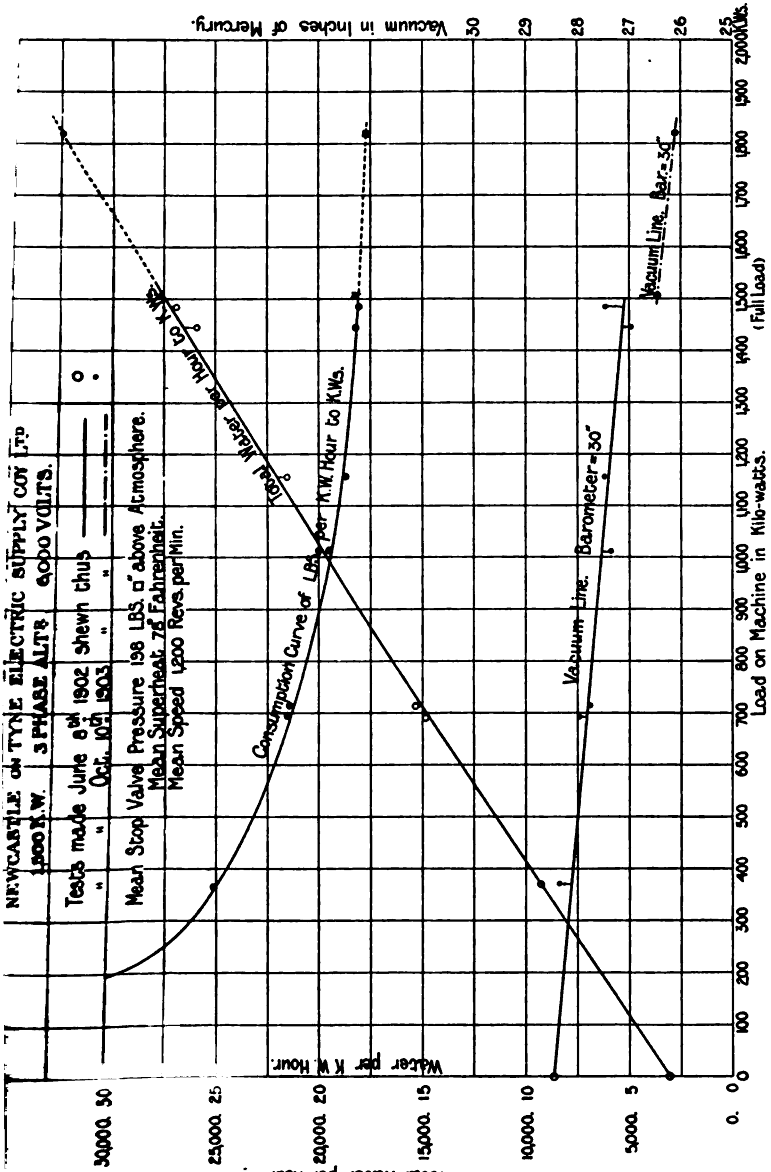
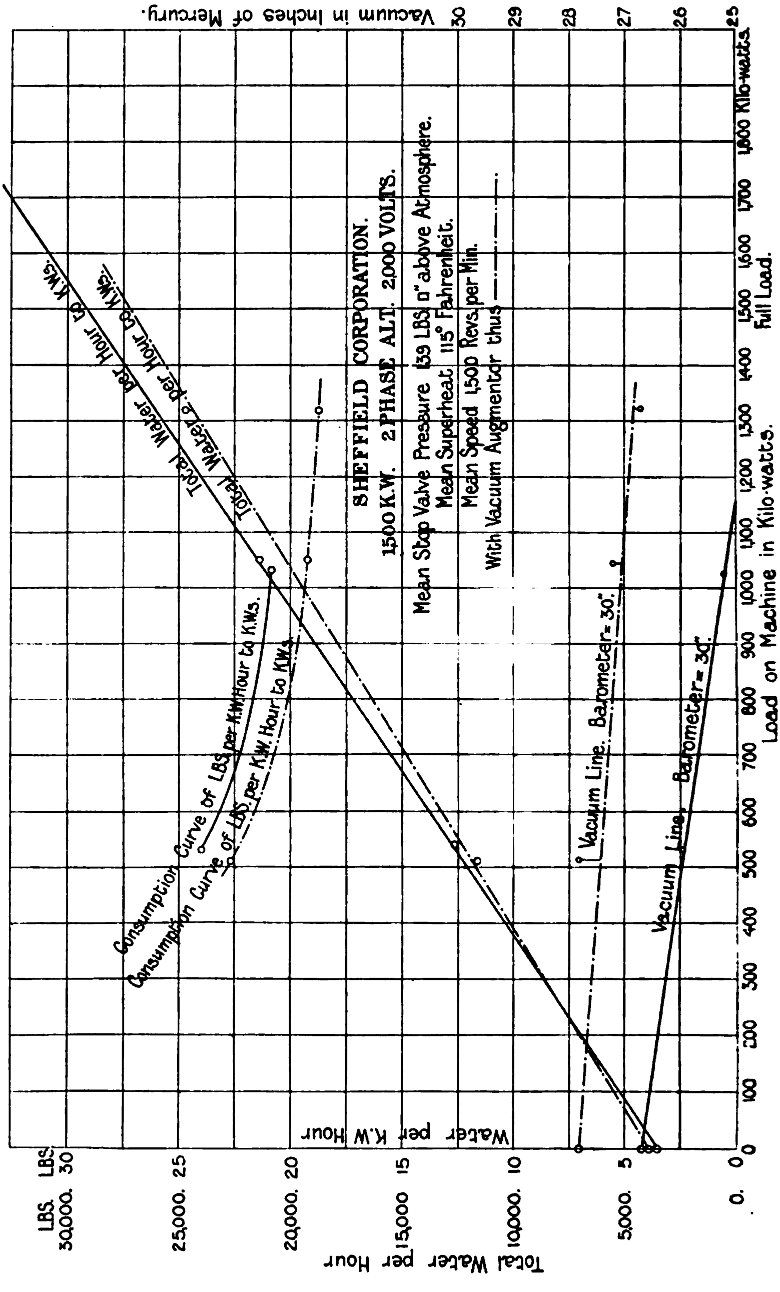


FIG. 6.

small quantity of air which must leak in. By attention to these requirements it is unnecessary to increase the size of the condenser beyond that



Vacuum in Inches of Mercury.
SHEFFIELD CORPORATION.
1500 K.W. 2 PHASE ALT. 2,000 VOLTS.
Mean Stop Valve Pressure 139 LBS. 0" above Atmosphere.
Mean Superheat 115° Fahrenheit.
Mean Speed 1,500 Revs. per Min.
With Vacuum Augmentor thus
Total Water per Hour to K.Ws.
Total Water per Hour to K.Ws.
Consumption Curve of LBS. per K.W. Hour to K.Ws.
Consumption Curve of LBS. per K.W. Hour to K.Ws.
Vacuum Line. Barometer = 30".
Vacuum Line. Barometer = 30".
Water per K.W Hour
Total Water per Hour
Load on Machine in Kilo-watts.
Full Load.
Kilo-watts.

FIG. 7.

used in ordinary practice, so that in the case of the most recent condensers for steam turbines from 10 to 12 lbs. steam is condensed per square foot per hour; and at this rate of condensation, vacua of from $27\frac{1}{2}$ in. to 28 in., with barometer 30 in., can be obtained at full load. The amount of cooling water generally allowed is about fifty times the full-load steam consumption, which will increase the vacuum under normal conditions by about $\frac{3}{4}$ in. or 1 in. over that obtained by the usual thirty times the steam used. If we allow 14 feet total head on the circulating pump due to lift, and for friction in the pipes and condensers, etc., which in most cases is excessive, especially where the return pipe is sealed, with fifty times the steam consumption in a plant taking 18 lbs. steam per k.w.-hour, and assuming 50 per cent. efficiency in the pump and motor, the power used by the circulating pump is only 1 per cent., and with circulating water thirty times the steam consumption it would be 0·6 per cent., a difference of only 0·4 per cent., such a small difference as not to be comparable with the gain of 4 per cent. to 5 per cent. in the turbine by the use of increased circulating water.

With regard to extracting the air, a great improvement has been effected by the use of a vacuum augmentor which has been recently introduced. In it the air-pumps are placed about 3 feet below the bottom of the condenser (see Fig. 9). From any convenient part of the condenser, preferably near the bottom, a pipe is led to an auxiliary condenser, generally about $\frac{1}{20}$th the cooling surface of the main condenser, and in a contracted portion of this pipe a small steam jet is placed which acts in the same way as a steam exhauster, or the jet in the funnel of a locomotive, and sucks nearly all the residual air and vapour from the condenser and delivers it to the air-pumps. A water seal is provided, as shown on Fig. 9, to prevent the air and vapour returning to the condenser. Thus if there is a vacuum of $27\frac{1}{2}$ in. to 28 in. in the condenser, there may be only about 26 in. in the air-pump, which therefore need only be of small size, the jet compressing the air and vapour from the condenser to about half or a little less of its original volume. The small quantity of steam from this steam jet, which is only about $1\frac{1}{2}$ per cent. of that used by the turbine at full load, together with the air extracted, is cooled down and condensed by the auxiliary condenser, which is generally supplied with water in parallel with the main condenser. In this connection it should be observed that condensation in a condenser takes place much more rapidly and effectually if the air is thoroughly extracted than if there is much air present, as the air seems to form a blanket round the tubes and retards the steam getting to them. In Table II. on p. 799 and Fig. 7, are given two curves of a test on a 1,500 k.w. plant for Sheffield, showing the difference of consumption with and without this augmentor; in these figures are included the steam used by the augmentor, which amounts to 450 lbs. per hour. The difference of vacuum is also shown, and when it is remembered that the augmentor jet only took about $1\frac{1}{2}$ per cent. of the full-load steam consumption, it is easily seen from the gain of vacuum where the total gain by the use of the augmentor comes in. In this case the vacuum was not as good as it should be, as the cooling water was 85° F., and was only about thirty times the steam consumption at full load.

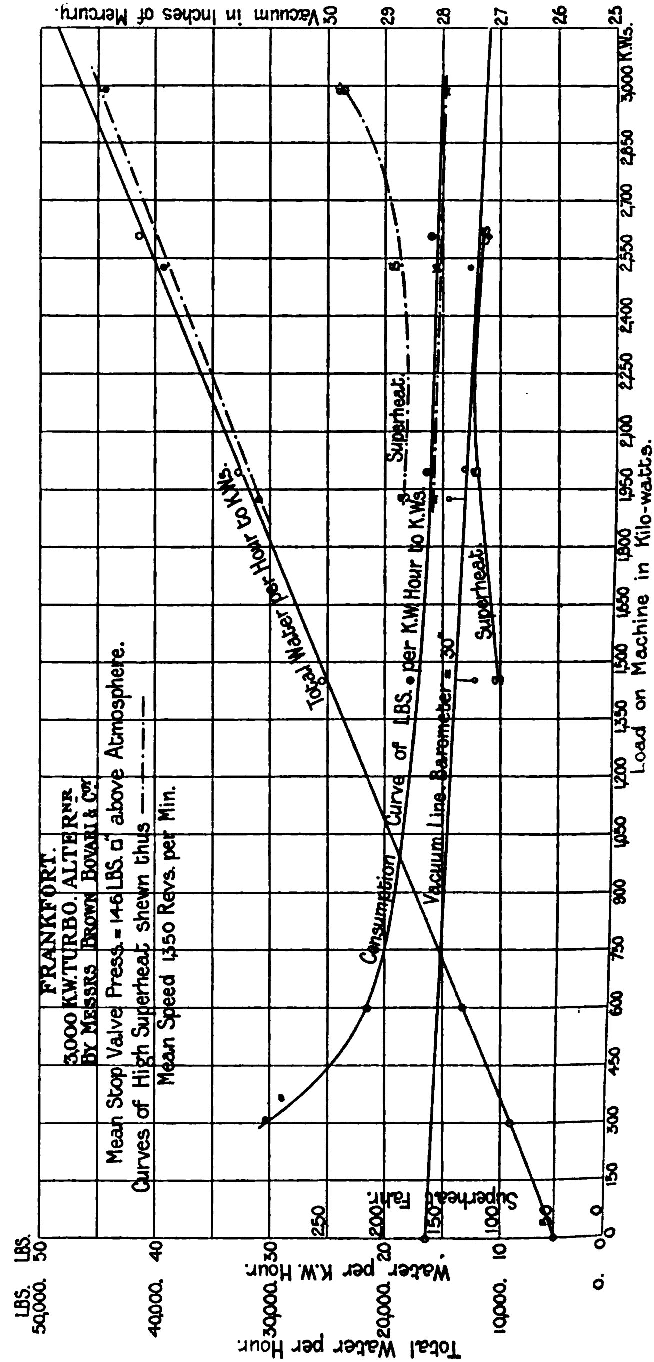

FRANKFORT.
3,000 K.W. TURBO. ALTERNR.
BY MESSRS. BROWN, BOVARI & COY.
Mean Stop Valve Press. = 146 LBS. □" above Atmosphere.
Curves of High Superheat shewn thus —·—·—
Mean Speed 1,350 Revs. per Min.
Total Water per Hour to K.Ws.
Consumption Curve of LBS. per K.W. Hour to K.Ws.
Vacuum Line. Barometer = 30"
Superheat.
Superheat.
Vacuum in Inches of Mercury.
Superheat Fahr.
Water per K.W. Hour.
Total Water per Hour.
Load on Machine in Kilo-watts.
LBS.
LBS.
50,000.
40,000.
30,000.
20,000.
10,000.
0.
50
40
30
20
10
0
250
200
150
100
50
0
30
29
28
27
26
25
0
150
300
450
600
750
900
1,050
1,200
1,350
1,500
1,650
1,800
1,950
2,100
2,250
2,400
2,550
2,700
2,850
3,000 K.Ws.

FIG. 8.

With reference to the original efficiency of a turbine being maintained, we may refer to the two sets of tests of the Newcastle Electric Supply Company's 1,500 k.w. after an interval of 16 months, as shown in p. 799 and Fig. 6, when it will be seen that absolutely identical results were obtained in the two tests. Careful examination of the blades of some of the original machines proves that, provided the velocity of the steam is not excessive, as it is not in the Parsons turbine, there is absolutely no cutting action on the blades.

In steam turbines the governing is effected either by a centrifugal governor of a well-known type, which keeps the speed constant, or by a core sucked into a solenoid to keep the voltage constant. In most cases, however, the centrifugal is preferable, especially where there are large changes of load, as in traction work, and it is also preferable where alternators have to run in parallel. In either case the governor

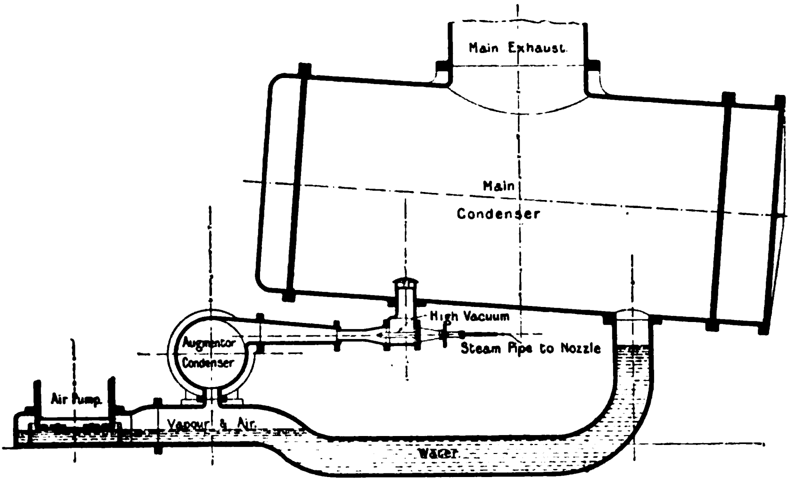


FIG. 9.—Arrangement of Parsons' Vacuum Augmentor.

moves a small relay plunger which regulates the steam, admitted to a relay, which in turn actuates the main admission valve, generally of the balanced double-beat type. The exhaust from the steam relay is utilised for the steam packing the end glands. Thus the governor having only to move the small plunger has very little work to do, and therefore can be made very sensitive. The sensitiveness is still further increased by keeping the whole governor gear in slight movement by connecting one of the pivots of the levers with a cam. These movements are so rapid as not to affect the even turning moment of the turbine. For parallel running of alternators, an even turning moment is of great importance, and this makes the turbine specially suitable for the driving of alternators. It might be thought that there would be difficulty in making alternators driven by reciprocating engines parallel with turbines, and *vice versâ*, but in no case has the running not been satisfactory, and in

some—for example, Elberfeld—the turbines have been found to steady the reciprocating engines. In this regard we may quote from a letter from Mr. W. H. Lindley, M.I.C.E., of Frankfort-on-Main, in which he says: "It is surprising to see two plants so entirely different in their speed characteristics parallel with such complete facility—the turbo running on no load and the Sulzer engine loaded, as the case may be, from quarter load to full load. When paralleled, we find the turbo alternators steady the steam engines, and thus favourably influence the tension in our lighting supply."

It is important to note that as in these steam turbines there are no rubbing surfaces, there is no need for internal lubrication, and therefore the exhaust is absolutely free from oil. So much is this the case, that in many instances the steam condensed is used as distilled water for delicate chemical work, where the smallest trace of oil would be fatal, and also for heating in breweries and other places. This also enables the condensed steam to be returned direct to the boilers without any oil filters being used.

In the design of dynamos and alternators to be coupled to steam turbines, special regard is to be paid to the large centrifugal force to be encountered. Diameters have to be kept down, and excessive surface speed must also be avoided. Since then, the diameter has to be small, the length must be increased in proportion and a long core is the result, with moderate diameter, the contrary of slow-speed machines. At the same time, on account of the higher surface speed, the pitch of the poles is greater, thus giving more ampere-turns per pair of poles than is usual. In alternators this gives no trouble at all, as all that has to be provided is sufficiently strong field magnets to overcome the reaction of the armature, and sufficient magnetic resistance to allow of strong field magnets. This extra magnetic resistance can be given either in the air-gap or by saturation of the poles as may be found desirable. These large poles also conduce to diminish magnetic leakage, and as a result very good regulation can be obtained. In low-voltage alternators rotating armatures are preferable, as the iron and copper losses are much less, especially where there are only two or four poles, but rotating armatures, although satisfactory for 500 to 2,000 volts, have not been found suitable for the higher voltages of 6,000 and 10,000 which are now common, and therefore rotating fields and fixed armatures have been adopted in many of the recent alternators. For continuous-current dynamos the same remarks apply, only here sparkless commutation has to be provided for. Carbon brush blocks cannot be used, as at these speeds the brushes are apt to vibrate, and so diminish the intimacy of contact and cause heating and undue wear. The result is that it has been found best to form the brushes of wire, gauze, or foil, preferably of brass, and these must be sufficiently flexible so as to maintain a good contact with the commutator over the whole section of the brush. It follows, therefore, that the properties of the carbon brush blocks in giving sparkless commutation without alteration of the lead of the brushes, cannot in turbine-driven dynamos be utilised, and other means must be adopted to secure sparkless commutation at varying loads. One way is to shift the brushes automatically

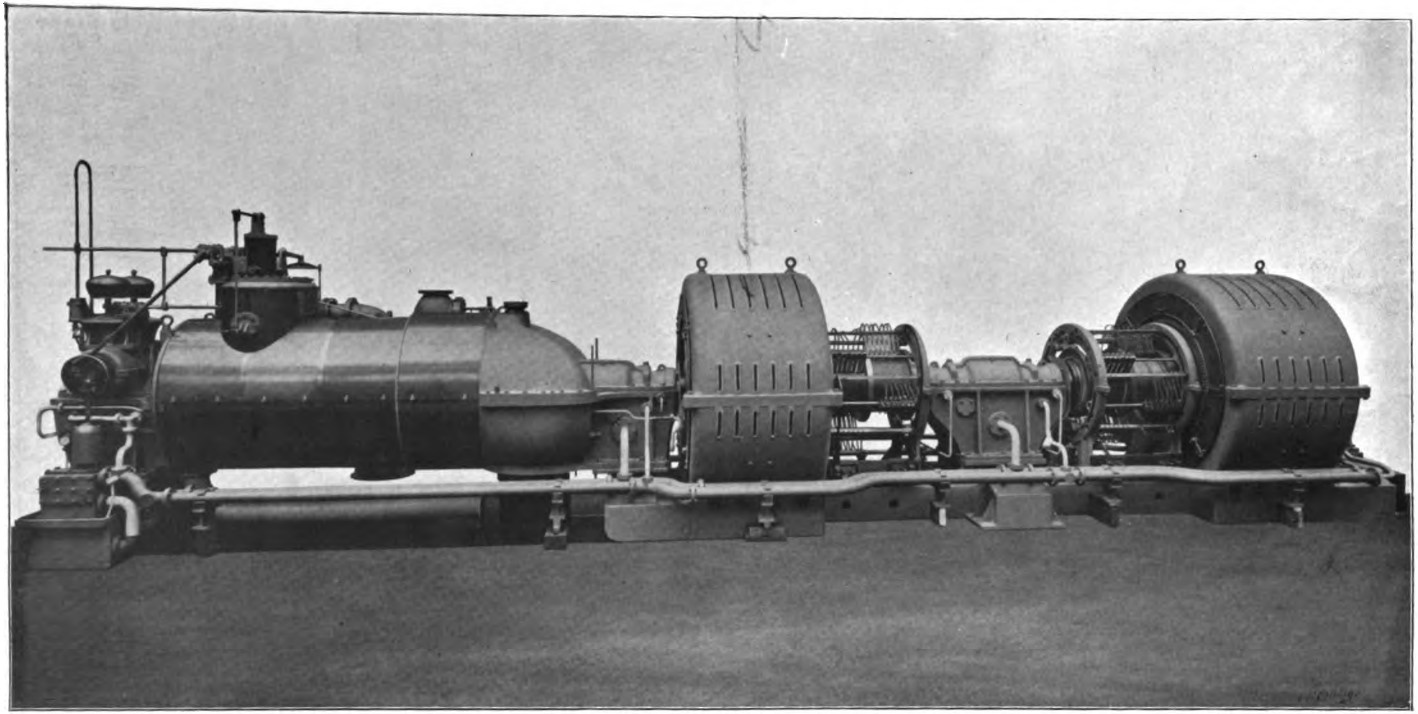


FIG. 10.—Manchester Corporation. 1,800 k.w. Continuous Current Turbo Generator.

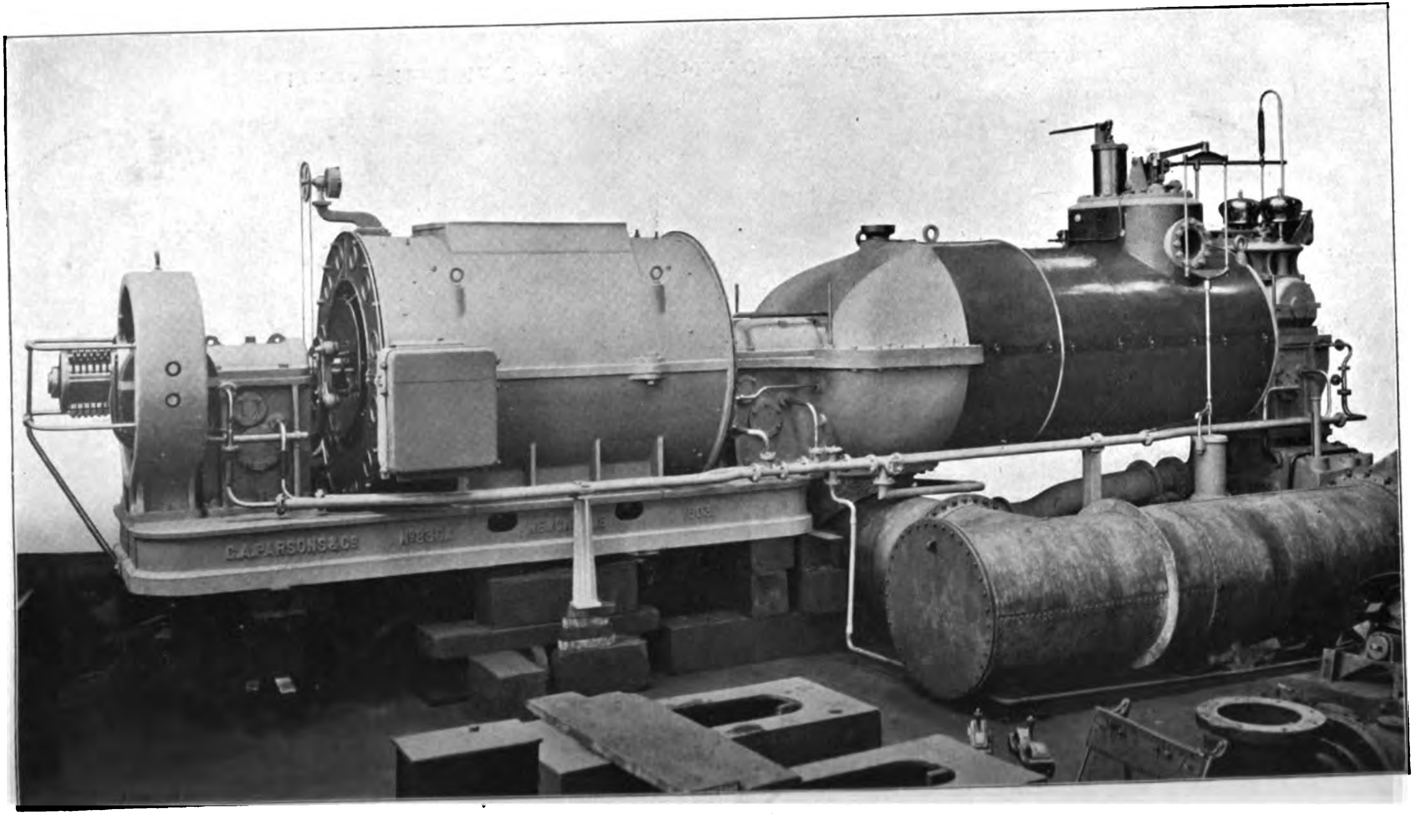


Fig. 11. Newcastle Electric Supply Co.'s 2,000 k.w. Turbo Alternator.

according to the change of load, and this can be effected by connecting the brush gear to a steam cylinder controlled by a spring and supplied with steam from the point where the steam enters the turbine. At this point the pressure of the steam is proportional to the load of the dynamo, and therefore the piston in the steam cylinder being controlled by a spring takes up a position proportional to the load and thus shifts the brushes to the point of sparkless commutation. Another method is to provide commutating poles as proposed by Professor Ryan and others, but the best method is to provide compensating winding as proposed by Professor Forbes, Deri, etc. By these means, with the improvements recently adopted, absolutely sparkless commutation can be secured with fixed brushes, up to, in plants for traction purposes, 100 per cent. overload.

The size of turbines is rapidly increasing, many of from 4,000 to 6,000 k.w. capacity now being in the course of construction, and it is anticipated that still larger plants will be made shortly. Up to the present there are about 600,000 H.P. of turbines of the Parsons type at work and on order in England and on the Continent, in various sizes ranging up to 7,000 k.w. In Figs. 10 and 11 are given two of the most recent types of turbo generators; Fig. 10 being one of the two 1,800 k.w. plants supplied to the Manchester Corporation for continuous-current supply at 420 volts, and Fig. 11 one of the 2,000 k.w. turbo alternators for the new Carville station of the Newcastle-on-Tyne Electric Supply Company, to give alternating supply at 6,000 volts, three-phase, 40 periods, for which station also two 3,500 k.w. plants are nearly completed.

It does not enter into the scope of this paper to describe the many other applications of the steam turbine—to marine propulsion, to the driving of fans, air compressors, blast-furnace blowers, etc., or to the lifting water to great heights by the use of high-speed centrifugal pumps, but it seems now certain that for many purposes, especially in large sizes, the steam turbine has become a most formidable competitor to the best reciprocating steam engines.

Mr. W. B. Sayers: I did not expect to have the honour of opening the discussion on this very important and most interesting paper; especially did I not expect it, as I do not propose to speak very much about turbines. I would like, however, to refer to one point about turbines. On page 807 the authors say: "Careful examination of the blades of some of the original machines proves that, provided the velocity of the steam is not excessive, as it is not in the Parsons turbine, there is absolutely no cutting action on the blades." I think it will be very interesting to know whether there is a critical point in velocity of steam at which cutting does occur, and whether it is found that in other forms of turbines cutting takes place. I now pass to page 808 of the paper, in which continuous-current dynamos are referred to. We read near the bottom of the page that carbon brush blocks cannot be used. It has been my experience to have been snuffed out in the earlier days by carbon brushes, and my hopes have risen a little on finding that carbon brushes cannot be used for steam Mr. Sayers.

Mr. Sayers. turbines. I would like to ask what amount of subdivision has been employed in the carbon brushes that have been used. I hear rumours of carbon brushes being quite practicable on turbines. I heard the other day of one firm which has used them, but they said they could not keep them running for more than two months or so. My friend Mr. Howitt has suggested that the solution of the use of carbon brushes may be found in a much greater sub-division of the blocks, and mounting each separate block so as to have the smallest possible amount of inertia. Then on p. 809 we read of the various devices which have been successful from the commutation point of view. We read: "By these means, with the improvements recently adopted, absolutely sparkless commutation can be secured with fixed brushes, up to, in plants for traction purposes, 100 per cent. overload." The arrangements which are referred to are by Professor Ryan and others, and by Professor Forbes, Deri, etc. (I, of course, have the honour to be included in the "others" and the little word "etc."; but I make no complaint of that, I merely remark it). This is rather a large statement, especially to one who has had, as I have, a very considerable experience in the use of devices of this kind, and of producing sparkless and fixed commutation by inductive means. It is rather a large statement to me that absolutely sparkless commutation up to 100 per cent. overload is secured by, as I understand, any one of these arrangements. I would be glad if the authors would be a little specific as to the arrangements which have been tried, and the duration of the trials, and as to any difficulties which may have been encountered. In that connection it might be interesting for me to give just a word or two of our experience. When I say our experience, I include Messrs. Mavor and Coulson of Glasgow, and Messrs. Jackson's of Manchester. Messrs. Jackson's have manufactured the machine with my winding, with a special arrangement of magnet poles which produces fixed brush position, under varying load. I will refer especially to machines which were fixed at Ashton-under-Lyne. These have an output of 350 kilowatts, and run at 210 revolutions; they are bipolar machines. For some years they were operated quite satisfactorily, that is, they could be maintained and made no real difficulty with metal brushes, but it was found that every now and then the commutators had to be attended to. It has been found that carbon brushes are an improvement on those machines, but the carbon brushes are considerably subdivided. The machines are on traction load, with large and rapid variations.

In our designs we find it important to keep the magnitude of the electro-motive forces dealt with as low as possible. In the design of modern commutating dynamos it has been found that the important point is to get the impedance of the coil under short-circuit or under the brush at the lowest possible figure. In our case it is not the impedance of the coil merely, but it is the magnitude of the error; that is, there may be a very near balance as regards percentages between the reversing force and the impedance—it never balances accurately, of course—but the magnitude of the unbalanced E.M.F. is a very im-

portant matter. Then I should like to refer to one arrangement which Mr. Deri uses on his machines, or at least I find it in his specification, namely, the use of the damping coil around the magnet poles. I would like to know whether that has been employed, because in the first case it shows that Mr. Deri anticipated the importance of keeping the impedance at a low value. I find that he claims in his specification No. 4,784, 1900, the use of such a coil. I tried substantially that arrangement in 1896 on an 80-kilowatt machine that I was testing at Messrs. Belliss's. I put a piece of copper along on the pole-tip in order to damp out the impedance due to the local field generated by my reversing coil, which it did to a large extent. But what I want to say about that is that Mr. Swinburne pointed out ten years or more ago that the impedance of the armature coil as a whole is very largely reduced by the field and armature windings, which are really short-circuited windings upon the circuit, and that the effective impedance is chiefly due to the local field around the conductors. It is therefore very necessary for any coil which is to have any substantial effect on the commutation, for that coil to be close alongside the coil which is under commutation. In a trial machine I recently proposed—but I was not able to get it carried out—the use of a closed coil which should follow, as far as possible, the contour of the coil under commutation, fixed in close proximity to the armature. That appears at first a little difficult to construct and fix satisfactorily. I suggested another way, which is to imbed as far as possible the end-windings in copper.* In the earlier days I was under the impression that the self-induction on end-windings was a very small thing, and almost a negligible quantity; but experience seems to show that is not the case, and it seems to me some device to reduce the self-induction of the end-windings, such as imbedding them in copper, or surrounding them as closely as possible with copper, might have advantageous results. Mr. Sayers.

The PRESIDENT announced that the scrutineers reported the following candidates to have been duly elected:— The President.

Member.

Robert A. Hadfield.

Associate Members.

John P. Clark.	A. Peden Rutherford.
Hedley L. Davis.	William. A. Wales.

* Since speaking, Mr. H. M. Hobart has drawn my attention to his references to the importance of the inductance of the end-winding in his paper, "Modern Commutating Dynamo Machinery," read September 5, 1901; also to patents which he holds for imbedding or enveloping the end-windings in copper.—W.B.S.

The Four Hundred and Tenth Ordinary General Meeting of the Institution was held at the Society of Arts, John Street, Adelphi, on Thursday evening, May 19, 1904—Mr. ROBERT KAYE GRAY, President, in the chair.

The minutes of the Ordinary General Meeting held on May 12 1904, were, by permission of the meeting, taken as read, and signed by the President.

The names of new candidates for election into the Institution were taken as read, and it was ordered that they should be suspended in the Library.

The following transfer was published as having been approved by the Council :—

From the class of Associates to that of Associate Members—

Charles William Lund.

Mr. J. Rance and Mr. F. Broadbent were appointed scrutineers of the ballot for the election of new members.

The discussion on Messrs. Parsons, Stoney, and Martin's paper, "The Steam Turbine as applied to Electrical Engineering," was then resumed.

Mr. Barker.

Mr. J. H. BARKER : I was not present at the last meeting, but I was somewhat surprised to see that the same old charge was raised against turbines, namely, the wearing of blades due to the action of the steam. If that impression still prevails, I may be pardoned for again expressing my ten years' experience of the use of turbines. For eight years I had charge of the same machines in daily use, and at the end of that time there was no visible wear on any of the blades. Two years after leaving the station I went there again; the engineer was good enough to open the machine and show me the blades, and they were in as good a state of repair as when they left the maker's works. The table of the consumptions published in the paper is a most valuable one, embracing as it does engines from 75 k.w. up to 3,000 k.w. capacity. Engineers can now see at a glance what they may expect to get from the installation of steam turbines. I have previously expressed my opinion that about 200 H.P. is an economical size to employ, and this table bears out what I have said. 135 k.w. here corresponds to about 200 H.P. with a consumption of 22·8 lbs. of steam per k.w. with 99°F. of superheat, that is, about 24½ lbs. with saturated steam, perhaps not as good as a reciprocating engine, but when the consumption of cylinder oil, which is equal to 5 per cent. of the coal bill, is taken into account it will be found that it works out as

economically as the best reciprocating engine on the market. The question of the value of the vacuum has several times been raised, and I am glad to find here that there is a definite statement which corresponds with my own view. The authors say that the effect of a 1 in. vacuum on a 100 k.w. engine is 3 per cent. Presumably this does not mean from 25 in. to 28 in., 9 per cent. in all, but if you take the percentage from 25 up to 26, 26 to 27, and 27 to 28, the average percentage works out about 3. Respecting the Newcastle-on-Tyne 1,500 k.w. alternator, with 18 lbs. of coal per k.w., during the discussion on Mr. Merz's paper I pointed out that the curve he had given was not quite as favourable as my own deductions led me to believe it would be, and the authors in this paper I note have brought it down to almost the identical figure I gave to the meeting, namely, 16 lbs. of steam per k.w. if the machine had been run up to 2,000 k.w. In connection with this it is interesting to compare the cost. I find the cost of coal at the Neptune Bank Station is 0·2d. per unit sold. Coal at £1 a ton is roughly 10 lbs. for 1d. The coal in question costs, I believe, 6s. 8d. a ton, or 30 lbs. for 1d., and 0·2d. is 6 lbs. of coal per unit sold, which, at 8 lbs. of steam per lb. of coal, is equal to 48 lbs. of steam per k.w. Let engine builders do what they will, they cannot appreciably improve on this. It is a question that demands the very serious attention of consulting and station engineers as to how they can reduce this abnormal amount of steam required per k.w. The test below, 14·74, is about the best result which has ever been obtained for steam-produced electricity, and is equal to ½ lb. of coal less than the Neptune Bank plant. Supposing this reduction were obtained, it is only 8½ per cent. on the 48 lbs. The augmentor is a new development brought before the Institution. Mr. Parsons was good enough to show me it some time ago, and I am very much interested to hear the result. A consumption of 450 lbs. of steam is equal to 20 H.P. of an air-pump. I should like to know from the authors if an additional 20 H.P. so applied would give the same increased efficiency that is given by the augmentor. Mr. Barker.

Mr. R. HAMMOND: I am the last person in this room who should speak at the opening of a discussion of a paper on Mr. Parsons' turbines, for, except in one isolated case, I have been one of the heretics who have not used them. In the case to which I refer, namely, the Hotel Cecil, we had to deal with very bad foundations, and it was necessary to put down a plant that was free from vibration. This may seem a very small place, but an installation equal to that of a small town was necessary. I feel glad, however, to have the opportunity of acknowledging the very great debt that the industry owes to Mr. Parsons for the battle which he has waged in favour of the steam turbine. Though he tells us that it would be beyond the scope of the paper to deal with anything but the application of the steam turbine to electricity supply, yet we are justly proud that one of our members has succeeded in producing a generator which is about to be used on the largest Cunard steamers. I have always felt some reluctance to adopt steam turbines in the past, because I have been afraid, as many other old-fashioned people possibly have been, Mr. Hammond.

Mr. Hammond.

of the wearing out of the blades; but the evidence which we now have before us, the magnificent results that have been achieved, and the favourable tests of machines which have been in operation for a considerable period, prove that we may freely banish this fear from our minds. I am glad at all events to be able to look Mr. Parsons in the face, and to say that it was due to me that the turbine was put into the Sheffield station. That was an instance where the Parsons turbine came in magnificently. They were very short of space indeed; they were in a great hurry for the plant, and the energetic gentleman who represents the Parsons' interests in London at once pointed out a very fine plant in the Paris Exhibition that could be sent over by parcels post, and be put down in about a quarter of an hour. The result was that the Parsons turbine was introduced into the Sheffield station, and worked so magnificently that when the station was extended, and the large new station was built, those turbines were adopted.

There is one point, however, which somewhat puzzles me, and in raising that point I hope Mr. Parsons will understand that my spirit is purely one of inquiry. I do hope that in the next specification which I issue I may see my way to specify the steam turbine out and out, and therefore what I say I do not say in a captious spirit at all, but with the desire to gain information. I am much impressed with the claim that the steam turbine is able to do without oil, and it occurred to me just before coming here to-night that I would put into my pocket the analyses of costs that have been made from time to time of the various undertakings in the United Kingdom. I was hoping to find that the places where the steam turbine was used were places which were marked by a great economy in oil. It seems obvious that if no cylinder oil is to be used, no cylinder oil would have to be paid for. I have no doubt Mr. Parsons will be able to give us a good explanation of this. I turned to Leeds—my favourite place when I am talking about costs. We have the engineer of the Leeds station with us to-night, Mr. Dickinson, and possibly he will be able to help us at a later stage in the evening. I notice that at Leeds the cost for oil, waste, water, and stores is 0·03 per unit. There are no Parsons turbines in Leeds; Leeds has been a place where they have very faithfully kept to the reciprocating engine. Wondering whether the economy in oil arising from the low figures in Leeds compared favourably with those of the Newcastle and district station, where the turbines have been used, I turned to Newcastle-on-Tyne, and I was somewhat surprised to find that the oil, water, waste, and so on at Newcastle costs 0·12 per unit. I am sure it would be very useful if it could be explained why the charge under the same heading should be four times as much at the Newcastle and district station. I turn to the place in which Mr. Barker was, and no doubt still is interested, Cambridge. Why is the figure there 0·14? That seems even more astonishing. Then there is Scarborough, with 0·08. Altogether I do not see in the actual analyses of costs so marked an exemplification of the fact that where the Parsons turbines are used the oil

Mr. Hammond.

bill is reduced to a minimum, and I should be glad to be enlightened upon that point.

With regard to condensing, I see there is a statement in the paper to the effect that it is well to use fifty times the amount of cooling water, that is to say, fifty times the amount of water evaporated into steam, rather than thirty. I fully appreciate the very great advantage which the turbine gets by the use of condensing, but I feel a little doubtful as to whether the very large amount of cooling water which must be used in order to gain the little extra vacuum is not going to involve us in much graver expenses than the extra vacuum is worth. My experience of central stations shows that it is the condensing arrangements which usually give us the most trouble; in fact, I hardly know anything connected with a central station which gives so much trouble as the condensing arrangements, which, though not perhaps very liable actually to break down, are certainly not often to be depended upon for maintaining vacuum at a level of 27 inches. I find that in all the trials recorded in the paper Mr. Parsons has been able, or those who have been using his plant have been able, to maintain the vacuum at even a higher rate. Nothing in connection with the central station is so difficult to maintain as that high vacuum. Of course there are places where, unfortunately, the necessity of using such an increased quantity of cooling water as is represented by the difference between thirty times and fifty times the steam makes the use of turbines prohibitive. I have had only recently to send a report to a place where turbines would certainly, from some points of view, have been most useful, but I was compelled to reject their use in view of the immense difficulty in obtaining the greater flow of water required to keep up the greater vacuum. I should like the authors to explain how it is that there is such a falling off in the efficiency at half load. In the controversies that have taken place from time to time with regard to the comparative efficiency of steam turbines and reciprocating engines, the tests at Leeds have often been referred to. It was my duty and pleasure to test two comparatively large sets of plants, that is to say they were sets of 1,400 k.w., side by side, one by Belliss's and the other by McLaren. I wish one or the other had been by Parsons. In connection with those two sets I found that while in the case of the Parsons turbine, as set out in this report, there is a falling off in the efficiency of 25 per cent. when run at half load, the falling off in the case of the Belliss engine at Leeds under the test was only 20 per cent., and that in the McLaren engine was only 13·6 per cent. As far as the actual percentage of steam was concerned, I may say that the Belliss engine, which showed the better results, gave 19·67 lbs. per k.w. as compared with the claim set forth in the paper of 18 lbs. for turbines under the same conditions of steam pressure and output. I feel, however, that it is only just to the Belliss engine to say that in those tests the water was measured into the boilers, and the 19·67 included the whole of the losses that occurred in the steam range as between the boilers and the engines, whereas I gather that in the case of the tests on the turbines the actual condensed water was weighed, so that in comparing the

Mr. Hammond.

19·67 lbs. with the 18 lbs. it is fair to deduct about 1 lb. from the 19·67 lbs. in order to represent the actual difference. It may be a stupid way of testing to have so many things in the line that are apt to rob the engine of efficiency, but at the same time, as a consulting engineer pronouncing a judgment upon apparatus which has to be used under certain absolute conditions, I have always felt—and my tests for the last ten or fifteen years have been conducted upon that basis—that any theoretical result which may be arrived at by doing what you never do in actual practice are of no use to me, and that it is better to test your plant under the conditions under which it is going to work from day to day.

Dealing with one other little point, I hope that before this paper finds its place in the Journal the authors will kindly amend the table which describes the results at Elberfeld. It may be only a very small point, but I notice that in Table I. the temperature of steam is given in degrees centigrade, and the steam pressure is absolute steam pressure, whereas in Table II. it is steam pressure above atmosphere, and then it is set forth in figures before the stop valve No. 2 in kilogrammes per centimetre. Members, Associate Members, Associates, and Students of the Institution would, I think, more appreciate the comparisons set forth in that table if they were more uniform with the tables that follow. But, on the whole, I do not wish to appear to-night in any carping spirit. No man in England will be better pleased than myself to be convinced that the turbine—I will say especially the Parsons turbine, because no man deserves success more than the Hon. Charles Parsons—is proved to be a more efficient machine than the reciprocating engine.

Professor Dalby.

Professor W. E. DALBY: The authors have emphasised the importance of working with a good vacuum, stating that even when using cooling water to the extent of fifty times amount of steam condensed, it is economical to use in addition a steam-extractor which takes $1\frac{1}{2}$ per cent. of the steam. Some curves which I have plotted in connection with the study of steam turbines emphasise the necessity of keeping a good vacuum in order to obtain the highest economy.

Mr. Parsons has stated that the steam flowing through a turbine falls in temperature and pressure very nearly according to the adiabatic law. Assuming, therefore, the flow to be adiabatic, consider first that steam at 160 lbs. pressure absolute per square inch flows into a chamber where the pressure is maintained at $1\frac{1}{2}$ lbs. per square inch absolute, without any obstruction in the shape of turbine blades. That is to say, imagine the turbine blades and vanes removed, and the areas of the successive cross-sections so arranged that the volume accommodates itself to the requirements of the flow. In these circumstances neglecting losses, the whole of the available energy of the steam is utilised in producing velocity. If J is joules equivalent 778, v the velocity of the steam when it flows from a chamber where the pressure is p_1 to another where the pressure is p_2, L_1 L_2, q_1 q_2, and h_1 h_2 the respective latent heats, dryness factors and water heats of the steam in the two chambers, the available energy of the steam may be approximately expressed as—

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$$q_1 L_1 - q_2 L_2 + h_1 - h_2,$$

and this must be put equal to $\frac{v^2}{2g.J}$ in the circumstances supposed. In this expression q_1 may be put equal to unity, assuming that the steam is initially dry, and q_2 may be calculated from

$$q_2 = \frac{\tau_2}{L_2}\left\{\frac{q_1 L_1}{\tau_1} + \log_\epsilon \frac{\tau_1}{\tau_2}\right\}$$

By giving a series of values to the subscript 2, the work available, the velocity produced and the corresponding volumes can be calculated. The following curves exhibit the pressure, the velocity, and the volume plotted against the available work calculated in this way.

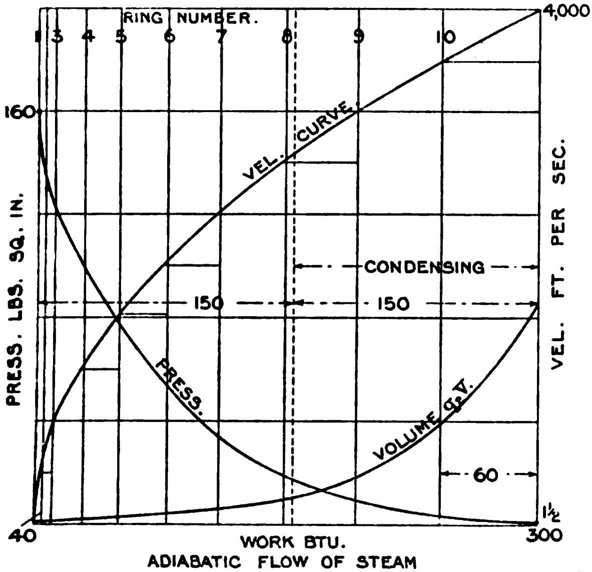

FIG. N

If now turbine wheels are put in the course of the steam so that the velocity is reduced to zero, this energy of flow is gradually transformed into mechanical energy.

Suppose the turbine shaft is fitted with ten rings of blades, and suppose that they are arranged as regards angle of exit, etc., so that each ring changes the velocity of the steam by one-tenth of the total velocity of flow. It will be apparent from the diagram that a ring of blades near the beginning of the series utilises a much smaller proportion of the energy of flow than a ring near the end. Thus at the first ring the pressure drops from 160 to 151 lbs. per square inch, that is 9 lbs. per square inch, and the British Thermal Units turned into work by the

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ring are only equal to 4 approximately. Taking the last ring, the drop of pressure is about 2 lbs. per square inch, but 60 British Thermal Units are turned into work by the ring. It will be noticed also that of the whole available energy, half, that is 150 British Thermal Units, is made available by the condensing plant.

The figures in the diagram are only worked out approximately, but they serve to give the perspective of the subject. In an actual turbine the proportions are affected by certain practical considerations which do not lend themselves to theoretical treatment. Bearing in mind the small amount of energy obtained from the steam by the blades at the beginning of the flow, what do the authors consider to be the highest steam pressure at which it is suitable to work a turbine, and is the efficiency much reduced in practice by cutting off some of the high-pressure rings? Also could the authors give data of the pressures measured along a turbine in order to compare them with the adiabatic pressures?

I should like, in conclusion, to add my congratulations to the many which Mr. Parsons has received in connection with the success of the steam turbine, a success which is entirely due to the investigations and persevering effort of Mr. Parsons and the authors. This paper, I venture to say, marks an epoch in connection with prime movers utilising steam. Here are given actual data of trials which compare with, and sometimes surpass, corresponding data from the reciprocating engine. I am sure Mr. Parsons must feel proud and satisfied that in the endeavour to wrest the supremacy of the Atlantic back to this country a committee of experts have decided that the surest means of wooing success is by the use of the Parsons steam turbine.

Mr. Insull.

Mr. S. INSULL: I feel some hesitation in appearing before you this evening, for the reason that I am not, strictly speaking, an engineer: my business is that of financing and operating central station lighting and power plants, and I cannot profess to go into the engineering details of the turbine in the same way as so many of your members. I am sure we all owe Mr. Parsons a very great debt of gratitude for the work that he has accomplished in connection with the development of the steam turbine. He, above every other man, whether on this or on the other side of the Atlantic, is entitled to the main credit for bringing the steam turbine to its present high state of efficiency. It has not been my good fortune to have any experience in actually operating his turbines, largely on account of the fact that it has been almost impossible to get large-sized turbines of the Parsons manufacture in the United States up to within a very short time. My experience has been confined mainly to what is known as the Curtis form of turbine, and that experience has only been during the last few months. In Chicago we have erected a turbine station, using, at the present time, three Curtis turbines, guaranteed to run at 6,000 kilowatts each. During the past winter we actually ran the first turbine that was supplied to us by the manufacturers on one occasion with a load of 7,800 kilowatts, and on another with a load of 7,500 kilowatts. We have not made any efficiency tests, nor have we made any actual maximum capacity tests. The loads which I have just spoken of were demands

made upon the turbine as a matter of necessity in the ordinary course of business, in order to help to take care of what you are so familiar with, namely, the winter peak load. Although I know so very little about efficiency, because we have made no tests, our experience in Chicago during the last few months completely bears out the experience of Mr. Parsons and his associates, so far as the economy of the turbine is concerned as compared with the reciprocating engine in ordinary central station practice from day to day. We have reasonably economical reciprocating engine stations, but we have been unable to operate our main reciprocating engine station, which has a capacity of some 17,000 or 18,000 kilowatts, at within about 30 per cent. of the cost of operating the turbine station. I am not prepared to say that this reduction in cost of working—and in speaking of cost I mean total station cost—is due entirely to the turbine; it is partly owing to the very much larger units that we have at work in our turbine station, and partly owing to the better design of our mechanical plant; but, in my opinion, mainly owing to the fact that the labour cost and miscellaneous expenses in a turbine station, if properly run, should form but a fraction of similar costs in a reciprocating engine station. So much for the question of cost of working. I hope in a few months we may be able to give you some figures on the efficiency of the turbine itself. Now as to the capital expenditures on plant; my experience is entirely with American prices on power-station plant; I know practically nothing about English prices; but taking American prices, and assuming large-sized units, say 5,000 kilowatt units, taking the cost of a reciprocating engine and the dynamo going with it, and comparing this with the cost of a turbine and the dynamo going with it, you cut the cost of the unit practically in half in a turbine station as compared with the cost in a reciprocating engine station. This reduction is affected to a small percentage by the increased cost of the condensing plant, but this is justified by the increased value that you get out of the condensing plant. Again, on the question of buildings, you can instal a given number of kilowatts in a station in a very much smaller space with steam turbines, whether the turbines be vertical, as of the Curtis type, or whether they be horizontal, as of the Parsons type—you can get very much more in a given space for the same investment in buildings. The result is that your interest cost is very much lower per kilowatt of maximum output, the capital investment is very much lower, and therefore it is easier to finance your enterprise. If the experience over a period of years should compare favourably with the tests made on Parsons turbines, and with our experience of turbines in Chicago, and if the low cost of our month to month operations should continue, which I see no reason to doubt, it would seem to me that the work on the steam turbine will occupy a relation to our electric power business second only in importance to the original work done by the early inventors in the development of the art. Mr. Insull.

Mr. H. H. DICKINSON: One point was mentioned by Mr. Hammond which I should like to emphasise; it is in reference to the difficulty that found in a practical way of maintaining the vacuum. It is all very well to say that you can maintain 27 in. of vacuum on your con- Mr. Dickinson.

Mr. Dickinson. densing plant, but in Leeds we have found very great difficulty in doing it. Our condensers are put in, I may say, with a very large cooling area, but we find the circulating water is dirty, and it fouls the inside of the tubes very rapidly. We have to sponge every tube through once a week, and still we cannot keep the 27 in. or 28 in. of vacuum that is requisite for the best efficiency of the turbine. I feel certain that in many cases where turbines are used there must exist the same difficulty that we find in maintaining the vacuum. We have also had trouble with the oil from the exhaust, but by using exhaust oil separators we have pretty well got over that difficulty. I think, as far as I am able to judge, the main advantage that a station engineer has to look to is the saving in capital cost. I think if you take everything into consideration there is not much at present in steam economy in comparing the turbine with the reciprocating engine, though, of course, turbines may ultimately give very much better results. The capital costs are the greatest. Take, for instance, the Leeds costs. The total works costs, as given in the *Electrical Times*, work out at 0·89; the capital cost, that is interest and sinking fund, works out at 1·9d. per unit, or a total of 2·79d. per unit. That seems an enormous figure, but it is an actual fact, and if you can reduce the capital cost figure you will save very much. Mr. Merz in his paper also called attention to the importance of reducing the capital cost as much as possible.

Mr. Fox. Mr. E. J. Fox: I should like to make a few remarks on this very interesting paper, and my comments will cover the points raised by the last speaker, Mr. Dickinson. Taking first the question of condensing, I cannot help thinking that in dealing with this new form of prime mover, the question of condensing is likely to prove more serious than appears at first sight. On the one hand, it is felt among many engineers that condensing has been pushed too far in many reciprocating engine stations, and that the cost of condensing, due to the very light loads prevailing in lighting and traction stations, is frequently greater than the savings introduced thereby. On the other hand, when coming to turbines, we see at once that condensing is a *sine quâ non*, and what is more, that we have got to expend a good deal of extra power in this direction: in other words, the cost of condensing is coming out a good deal heavier without any appreciable benefits so far as steam consumption is concerned; for, as I will show in a minute or two, the steam economy obtainable with turbines, except in the very largest sizes, is not superior to those obtainable with reciprocating engines at the present time. We have, therefore, to face the situation of expending more money on condensing in order to obtain these higher vacua, without getting any appreciable benefits in steam economy, and for these reasons I think the whole question of condensing deserves greater attention than it sometimes gets. I was talking a day or two ago to one of the leading condensing engineers in this country who had gone into this question of maintaining high vacua at a minimum expenditure of power, and he was very much of opinion that in many cases the cheapest way of maintaining these high vacua was not with surface condensers, the type usually installed, but with a modified form of jet condenser, namely, the counter-current jet condenser, arranged

Mr. Fox. with the exhaust steam and the condensing water travelling in opposite directions, the condenser proper being fixed on the top of a barometric column about 34 feet high, and arranged with a dry-air pump, and a circulating pump for lifting the condensing water. Of course that type of condenser has the advantage of requiring a smaller volume of water, hence less cost of power for circulating, etc.; but, on the other hand, the heat in the water is largely lost. I understand that in the Clyde Valley scheme which the Westinghouse Company are carrying out turbines are being used, and this type of condenser has been adopted in preference to the surface condenser, on the grounds of cheapness in working. There are certain objections, I suppose, in having the condenser removed from the turbines, but at the same time with properly made joints, and with the exhaust pipes large enough, there should be no difficulty in maintaining a high vacuum on the turbine itself with the condenser some distance removed. I was rather interested to see the other day in an iron works in the north of England, a vacuum of 26½ in. being maintained along an exhaust pipe 6 feet in diameter, 250 yards long, and with air-pumps 250 yards distant from the engines. There was certainly a drop of about 1 inch in the vacuum from the one end of the pipe to the other, but still it shows that with properly made joints there is no insurmountable difficulty in maintaining a good vacuum even at a distance. It would be interesting to hear whether the authors have had occasion to pay attention to this form of condenser. The only other point I would like to touch on is the question of steam consumption. I think we have heard enough this evening, from Mr. Insull in particular, to convince even the most biassed that on commercial grounds the installation of turbines has been justified in all the larger sizes. It is perhaps scarcely just to criticise, as one is inclined to do, one or two items of cost, out of a number, and at the same time ignore the total costs. I think, however, in justice to the reciprocating steam engine I should like to say that, taking the figures of steam economy as given in the paper as obtainable with the different sizes of turbines, there is no difficulty whatsoever in the reciprocating engines giving equally good results up to the 1,500-kilowatt size mentioned. From 100 up to 1,000 kilowatts the results obtainable with reciprocating engines are better. When you come to the 1,500-kilowatt size there is very little difference between the two; and finally, with the 3,000-kilowatt size I think there is no doubt a considerable difference in favour of the turbine. I am talking of reciprocating engines working with moderate degrees of superheat under similar conditions to the turbines, though with somewhat higher steam pressures. But to get the best results from reciprocating engines you have to go a step further and have higher degrees of superheat, and the reciprocating engine will gain more with increasing superheat than will the turbine, thus giving the reciprocating engine a further advantage over the turbine in steam consumption. For instance, on some recent tests which were made on quite a small 200 H.P. Willans engine a consumption of 10 lbs. of highly superheated steam per B.H.P. was obtained, which is equivalent to 14½ lbs. per kilowatt. These results can be reproduced any day under similar conditions, namely, 260 degrees superheat, with a boiler

Mr. Fox pressure of about 190 lbs. So I think as far as steam consumption is concerned, the reciprocating engine can certainly hold its own at present, especially if engineers adopt high superheat and high boiler pressures in the same way that they are adopting high vacua in connection with turbines. As I have said before, it is scarcely fair to take hold of one item in the way I have done, namely, coal consumption, and in the way Mr. Hammond to a lesser extent has referred to the item of oil, waste, water, petty stores, etc., whilst ignoring the total works costs, which include the various capital charges. No doubt many of the leading engineers in this country, and also on the other side of the water, consider that in the larger sizes, at all events, the capital costs alone more than justify the installation of turbines even at the present time, and I am sure it must be a matter of great gratification to Mr. Parsons to see the way in which the leading engineers of this country have taken up his turbine, and also the way it has been taken up in the States and on the Continent. The world at large is very much indebted to him for the work he has done.

Mr. Merz. Mr. C. H. MERZ: It is particularly opportune at the present moment, when most engineers in this country are beginning to realise that, at any rate for large sizes, turbines are the things to use, that Mr. Parsons and his associates should give us a paper describing the progress that has been made with turbines since the beginning. The question of costs has come up in the present discussion, as it always does, and rightly to a great extent, but the costs obtained have been criticised, as the last speaker mentioned, from the point of view of the individual items and not from that of the total costs. If engineers will discuss costs on the basis of total costs in the full sense of the word, then I unhesitatingly think they will find that the turbine is the thing to adopt at the present moment, in all sizes which interest station engineers who are distributing power or light over large areas. It is particularly interesting to watch the gradual conversion of engineers to the turbine. I myself was converted some years ago now, when Mr. Parsons first made turbines of large size, and when I had the privilege of seeing the Elberfeld machine tested. Before that time I was somewhat sceptical myself as to the economy of turbines. Since then engineers have gradually admitted that turbines will enable them to sell electricity, through a saving of capital, at a lower cost; and I think before another session of the Institution has come round, even those engineers who are still somewhat sceptical as to the benefit of turbines will have changed their minds. The vacation is always a good time to change one's mind on such points.

During the discussion on my paper, which was read two or three evenings ago, one or two speakers particularly asked as to the results which were being obtained with the Curtis turbine. Mr. Insull has told us to-night of the practical results obtained, but he did not allude to steam consumption. I happen to have recently installed a Curtis turbine in Cork, and although it is of comparatively small size, perhaps you will be interested in hearing the results obtained with it. The machine was a 500-k.w. turbine, direct-current. At full load, with a vacuum of 27 in., a superheat of something slightly over 100° F. and a

Mr. Merz.

steam pressure of 150 lbs., we obtained a consumption of about 20·5 lbs. of steam per k.w.-hour. You will notice that the vacuum was low. Correcting for vacuum and superheat, and bringing the latter up to 115° F., and the vacuum up to 28½ in. (which I certainly think can be maintained with river water), it will be found that the steam consumption is equivalent to something under 19 lbs. per k.w.-hour. This, I think, is a very good result. It will be seen that the Curtis turbine is capable of producing electricity with at any rate as low a steam consumption as the Parsons turbine. As to which of the two types is the correct one will, therefore, to a large extent depend, I presume, upon the cost of repairs, and the cost of oil, and such auxiliary items. I cannot myself speak of the repairs of the Curtis turbine, because we have not had one operating long enough. I can speak as to the repairs of the Parsons turbine, because we have had large machines operating on the Tyne for the best part of three years, and I referred to these results as obtained from a Parsons turbine in the paper which I read two or three meetings ago. One or two speakers have referred to the difficulty of obtaining high vacua. This, I think, is because they judge the matter from the use of reciprocating engines. If you will adopt turbines, and put your condenser directly below the turbine, or, if you install a Curtis turbine and combine the condenser with the turbine, you will find no difficulty in maintaining high vacua, given a proper supply of cooling water. Of course, with a cooling tower you cannot get quite the same results, because unless you face a very large expenditure on cooling plant, the condensing water will be at a somewhat higher temperature than river water; but I do not think even in such cases there will be any difficulty in obtaining and maintaining a vacuum of 28 in., assuming a 29½ in. or 30 in. barometric pressure. In discussing the relative economy of steam turbines and steam engines, therefore, I think you may quite well assume that a vacuum of 28 in. or even 28½ in. can be maintained with turbines under practical conditions, even though it may not be obtainable with reciprocating engines. The authors have told us in their paper of the augmentor condensers which they have recently perfected for assisting in the maintenance of high vacua. I must say that from the figures given I do not think they make a very good case for it. If one goes in for the complication and the extra expenditure which such an arrangement represents, even if not in first cost certainly in maintenance, one expects to get something better than the ordinary vacua which can be obtained with a simple Edwards air-pump. In Cork the other day, when we were testing the Curtis turbine, although we had a bad vacuum in the turbine exhaust chamber itself we had an extremely good vacuum in the condenser, and we had only an ordinary Edwards air-pump. We got to within 1 in. of barometric pressure. I think, therefore, it would be most interesting to hear from the authors by what amount they really expect to increase the vacuum under working conditions with this somewhat complicated device. It would also be very interesting to hear from them as to whether they have had any experience of the use of jet condensers, as referred to by the last speaker. The use of jet condensers is practically precluded in all

Mr. Merz. cases where salt water or river water is used, but in cases where cooling towers have to be used, and where, therefore, there is not much objection to mixing the boiler feed with the condensing water, it would seem that if there is anything to be gained in capital cost by the use of jet condensers they should be adopted, provided sufficiently high vacua can be obtained with them. The only other thing I might mention is the question of direct-current machines for use with turbines. This is a question which is still in a stage where every one has a different idea as to their practicability. I must say that I personally think no continuous-current machine is worth having if it cannot be operated with carbon brushes, and I do not know that the authors have stated in their paper exactly how far they have succeeded in using carbon brushes on large sizes. In the particular machine to which I have referred before, the Curtis turbine at Cork, which is of comparatively small size, namely, 500 k.w., carbon brushes are used with considerable success. During the time I was making the tests on the turbine, some oily waste got between the brushes and the commutator by accident, resulting in the commutator flashing over. It, however, cleared itself at once; there was simply a considerable noise, and the short cleared itself without any trouble at all. So that at any rate in sizes up to 500 k.w. it would seem that at speeds of 1,800 revolutions per minute or so, it is possible to design a continuous-current machine using carbon brushes.

Mr. Kilburn Scott. Mr. E. Kilburn Scott: One difficulty which is met with in some stations is that the cooling water for the condenser is taken from a canal, and it is used by so many firms that in the late afternoon, when a good vacuum is most required, that is to say when the lighting and power loads are overlapping, the water is quite warm. Again with cooling towers it is quite common for the vacuum to drop off in the hot days in summer. Now there is a little apparatus used in the East for drinking water—I have one at home—which has given me an idea. It is the ordinary unglazed porcelain vessel for drinking water, and one can always be sure of getting icy-cold water from such a vessel, and the hotter the day the colder the water. It seems to me that the idea might be adopted in connection with cooling towers by having a considerable system of unglazed earthenware piping through which the water would pass. In the hottest days with the sun playing down on the pipes there would be considerable sweating, but one would be sure of getting much cooler water.

(*Communicated.*)—About fourteen years ago it was my fortune to be in charge of the drawing office of the steam turbine and electrical department at Clarke, Chapman & Co., just after the Hon. C. A. Parsons had left that firm to establish new works at Heaton. My recollection of the steam turbine of those days is a nightmare, and to see it the perfected machine it is to-day makes my admiration for the inventor and those associated with him all the greater. I recollect that one of our troubles was with the delta metal rings. We would cut out a set of blades and then find a flaw in the metal. That was bad enough luck, but it was much worse if the flaw developed when the machine was under test, as one broken blade generally cut out several complete

Mr. Kilburn Scott.

rings. By adopting separate blades caulked in, this difficulty appears to have been got over. Another difficulty in those days was in not having machine tools of sufficient precision, and various dodges had to be adopted to make up for these shortcomings. I think it may be fairly said that the excellent results of modern turbines are largely due to great improvements in machine tools, which have fortunately synchronised with steam turbine development.

As a further tribute to the Hon. C. A. Parsons I should like to add that he is not only a clever engineer in theory and design, but is also an expert handicraftsman. Many of the parts of the first steam turbines he made with his own hands, and I have heard expert armature winders acknowledge that he could beat them at their own trade. I believe it is a fact that he wound the first barrel-type armature ever made. Whilst other firms were for years pottering along with the "go as you please" drum winding, the Parsons dynamos were being made with a scientific and accurately balanced winding practically identical with the barrel winding of to-day.

I should like to ask the authors a question regarding the steam blast form of turbine which, I believe, was developed to get round the original patents which (as the result of a lawsuit) remained in the hands of Clarke, Chapman & Co. These patents were eventually bought back and the steam blast was dropped, but it always appeared to me as being a very clever idea to govern by varying the number of successive blasts of steam in a given time. If ever there is to be a gas turbine it will no doubt be somewhat on these lines, and I am sure the authors would confer a benefit if they could see their way to give some details of the working of turbines embodying this blast idea.

I alluded above to some of the old troubles with blades, and even now I believe they sometimes get loose. It may be of interest to mention that there is a turbine, the "Bucholz," which has *no* blades, and has the further somewhat remarkable feature that it is reversible. I have described this turbine,* but may here state that it consists of a number of metal discs, half of them strung on a rotatory spindle and half fixed inside of the casting of the machine. In the fixed discs a series of concentric holes are drilled at right angles, and in the rotating discs there are a similar series of holes, but these latter are drilled through at a considerable angle with the plane of the disc. In passing through the series of discs the steam is thrown against the slanting holes, and so causes the discs to rotate. When the steam has passed through the series nearest the periphery, it works back through the next series of holes nearer the spindle, and so on, forwards and backwards, until it finishes at the end of the row of holes nearest the spindle. By admitting the steam at the spindle and exhausting it at the periphery the turbine rotates in the reverse direction.

Professor Ayrton.

Professor W. E. AYRTON: I certainly join with the previous speakers in admiring Mr. Parsons' boldness, I may almost say Mr. Parsons' audacity, because it was only some fifteen or eighteen years ago that he showed in one of the exhibitions at South Kensington—the Health or Inventions Exhibition, or whatever it was—the first steam

* *Electrical Review*, January, 1904, p. 66.

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turbine. My laboratory was adjoining the Exhibition, and I frequently used to hear the comments that were made about that turbine—"steam-eater," "scientific toy," etc., etc.; and nobody imagined, except probably Mr. Parsons himself, that that "steam-eater," that "scientific toy," would ever be a competitor of the reciprocating engine. Years afterwards, in fact only four years ago, at the Paris Exhibition, I had to go somewhat fully into the engines in the British exhibit, and I was very interested to find that of all the steam engines in the British exhibit the Parsons turbine was the one taking the least amount of steam per k.w.-hour. Somewhat more recently I had to express an opinion about turbines *versus* reciprocating engines in a case where the adoption of the turbine might lead to the adoption of a very large number; and I therefore had to assure myself that not merely was the amount of steam consumed per k.w.-hour, as shown by tests when the steam turbine was new, extremely low, but was that low consumption maintained after some years of work? It may be remembered that Professor Ewing made two sets of experiments; he allowed an interval of a year, or some such period, to elapse, and he found that the initial low steam consumption was maintained. I made inquiries of various people on the Continent and elsewhere, of Mr. Lindley of Frankfort, and of various people whom I knew had used turbines, and I was extremely gratified to find that their conclusions were the same as Professor Ewing's, namely, that the low steam consumption that was obtained at the beginning was still maintained after some appreciable time of steady running of the turbines.

There is one advantage of the steam turbine over the ordinary reciprocating engines which nobody, as far as I remember in this discussion, has alluded to, and that is the quickness with which you can get up speed. You can start the steam turbine comparatively cold, and in a very short time it is running efficiently at full load. There is no warming up necessary, such as required with the well known reciprocating engine.

The two turbines that have been spoken of in this discussion and the discussion on Mr. Merz's paper are the Parsons turbine and the Curtis turbine. At the end of last year, when I was over in America I took the advantage of going—not, unfortunately, very fully, because my time did not allow of it—into the question of the Curtis turbine. I saw them being manufactured at the General Electrical Company's works at Schenectady, and I made various inquiries on the subject. As Mr. Merz said, the efficiency at full load—that is to say, the amount of steam per k.w.-hour—is about the same as with the Parsons turbine. It is claimed, however, that at a quarter load there is less steam consumption—that is to say, that the efficiency does not fall off as much as in the Parsons turbine, and the practical reason why that claim is made is the way in which the steam supplied is diminished. In the case of the Curtis turbine there are a number of separate nozzles through which the steam is introduced. The steam is not partially shut off in any one particular nozzle for diminished load, but it is entirely turned off that nozzle, so that it supplies practically full steam or no steam at all; that is to say, a small steam consumption at low load is obtained

by simply having fewer nozzles fully turned on; hence there is no loss of energy from wire-drawing. The figures that I obtained were, that a 500-k.w. turbine running at 1,200 revolutions used 18½ lbs. of steam. That is a little better than Mr. Merz obtained with a similar machine, even with the calculation of higher superheat and so on. As regards the falling off, I will take the actual turbines that have been referred to in the Chicago Central Station. The actual turbines in the Chicago Central Station, I understand, give these results—at full load 17½ lbs. of water per k.w.-hour, and that is only increased to 19 lbs. at quarter load. One of the great advantages, as I have already said, which is considered to be possessed by the Curtis turbine, is that even at quarter load the consumption is not seriously increased. The Curtis turbine is extremely frictionless. The lower end of the vertical shaft is in oil, at a high pressure, some 400 lbs. to the square inch—a very high pressure; and the result, I know as a fact, is that it is so beautifully balanced that you can turn the turbine round with one finger. But whether or not the Curtis turbine can compete with, or will surpass, the Parsons turbine, it is to Mr. Parsons that we owe the development of the turbine. It is to his determination, his seeing that a toy could, by sufficient labour, sufficient experiment, sufficient ingenuity of design, be developed into a machine (which, I venture to think, will displace the reciprocating engine for powers of 500 k.w. and upwards) that we owe the practical steam turbine of to-day. Professor Ayrton.

Mr. Leon Gaster: I congratulate the authors for their very interesting paper, and although I have no personal experience of steam turbines, I think that, in view of the world-wide importance of the subject, I may be allowed to give a few data actually obtained on the Continent, in the use of the Brown-Boveri-Parsons turbines. I should like to refer, amongst other articles written on the subject, to the very interesting article written by E. Scherenberg of Mannheim, which appeared quite recently in the *Schweizerische Elektrotechnische Zeitschrift* of Zürich, from which it appears that the steam turbine has come to stay as a very important factor in contributing to cheapen the generation of electrical energy. Taking the question of costs, it is estimated that the steam turbine of larger units, say above 1,000 H.P., is 30 per cent. cheaper in first costs than a reciprocating engine of the same capacity, which reduction is of considerable importance. The engine-room space occupied by a steam turbine is about a quarter of that of a steam engine of the same capacity; the necessary foundation is about a quarter smaller; the weight per H.P. averages from 15 to 25 kilogrammes for steam turbines, against 60 to 90 kilogrammes required per H.P. for steam engines. The oil necessary for lubrication is calculated at about 0·1 to 0·2 grammes per H.P. per hour, against 1 to 2 grammes used in reciprocating engines. In comparing an estimate where three engines of 1,800 H.P. each were required to run ten hours daily, it appeared that in adopting steam turbines instead of engines an economy of over £1,300 could be obtained from the reduction of size of the foundation only, and about £1,000 per annum would be gained from the reduction of lubricating oil. The fact of being able to take better advantage of superheated steam adds to the value of the Mr. Gaster.

Mr. Gaster. use of the turbine. The well-known Professor Dr. H. Weber, of Zürich, has made some tests on the 400-k.w. steam turbine erected at Tschöppelner Mine, and found that for each 6° centigrade superheating an increase of 1 per cent. in the efficiency of the steam was obtained, which figure corroborates the one given by the authors in their paper. The governing of the turbine has also been found very efficient. At a test made by Professor Dr. Weber conjointly with Mr. Struples, on a 300-k.w. steam turbine erected at the Electrical Central Station at Chur, in Switzerland, it was found that the speed fluctuations, with the variation of the load from 75 H.P. to 300 H.P., were very small, namely, for ± 25 per cent. load, the speed varied only 0·37 per cent., for ± 50 per cent. only 0·46 per cent., and throwing the load on or off from 300 k.w. to 100 k.w. the fluctuations were only 0·87 per cent., which were considered very satisfactory. The confidence placed on the Continent on the efficient working of the turbine is shown by the great number of turbines already erected and orders now in hand. With regard to the efficiency for different loads, I have here before me the results of about twenty installations of different sizes erected in Germany, Switzerland, etc., and it appears that by altering or running the turbines at three-quarter full load the steam consumption increases from 8 to 10 per cent. more than at full load, and running at half load about 20 per cent. more steam is used per H.P.; but, generally speaking, for very large units using proper vacuum and superheated steam, the consumption of steam has not been found much greater than that used by steam engines. The consumption of steam per H.P. varies of course with the size of the plant, and other conditions; but judging from the examples I have before me, the difference does not appear to be so great. The largest order in hand at present for a steam turbine installation to be erected by Messrs. Brown, Boverie & Co. is the one for the Société Parisienne de Tramways et de Chemins de Fer, Paris, where three turbines of 5–6,000 k.w. each and one of 3,000–3,600 k.w. will be erected and directly coupled to three-phase generators for 6,000 volts and 25 periods. One of the largest steam turbine units will be erected at the Electrical Central Station at Essen, in Germany; the turbine has a capacity of 8,000 H.P., and will stand temporary overloads of another 2,000 H.P., developing 10,000 H.P. at 1,000 r.p.m. This turbine will be directly coupled to a 5,000-k.w. three-phase generator and to a 1,500-k.w. direct-current generator.

At the Fifth Annual Meeting of the Steamship-builders held in Berlin, Mr. W. Boveri took part in the discussion of Professor Riedler's paper on the Riedler-Stumpf turbine, and pointed out that the steam consumption is less in the Parsons turbine than in the one described, and that there are many other advantages which speak in favour of the Parsons turbine.

Mr. Cramp. Mr. W. CRAMP: It seems to me that in our admiration of the skill and ingenuity brought to bear on the steam turbine we are likely to forget the difficulties overcome in connection with the dynamo. I beg to differ entirely from Mr. Merz when he says that no machine which runs without carbon brushes ought to be a success, and it is hardly fair

to assume that a brush gear is intended to stand having "*oily waste*" thrown into it. I think those of us who are interested in dynamo design owe the Hon. Charles Parsons, and those who work with him, a very great debt of gratitude for the development of the high-speed commutator with copper brushes. We were inclined to believe from Mr. Hobart's paper that in order to get satisfactory commutation with high speed, that is to say with probable high reactance voltage, we should need carbon brushes, particularly if the brushes were not moved from no-load to full-load. Now we learn, from this paper, that by means of extra windings you can get quite satisfactory commutation without moving the brushes, and with the use of copper brushes alone. I think that few engineers recognise the enormous loss that takes place due to the use of carbon brushes. In two cases lately, it has come within my experience—in connection with smaller machines than those mentioned in this paper—that the efficiency of the dynamo was lowered through the use of carbon brushes from 1 to 2 per cent. By the substitution simply of carbon brushes coated with copper, instead of plain carbon brushes (thus obtaining better contacts), the machine efficiency at full-load went up 1 per cent., which is a very great difference; and better results still may be obtained if carbon brushes containing a large percentage of copper are used. If you substitute pure copper in place of carbon I think you can raise the efficiency as a rule on moderate-sized machines of, say, 100 k.w. from 2 to 2½ per cent. If the losses in the extra windings used by Mr. Parsons do not rise to that value, you get a corresponding advantage by putting them in, provided of course that the initial cost entailed is not very great. I should like to ask those gentlemen who are responsible for the design of these dynamos, what the loss in extra windings is as compared with the loss in carbon brushes. Mr. Cramp.

Mr. W. H. PATCHELL: One point alluded to by Professor Ayrton I think is likely to come up with the turbine as much as it has arisen with the reciprocating engine, namely, throttling or variable expansion. Professor Ayrton said that the Curtis people told him that they preferred to cut out some of the nozzles. One of the leading Continental specialists told me quite lately that he preferred just the opposite thing, that he wire-draws, and gets better efficiency at low loads by wire-drawing than by reducing the number of nozzles. I think the speakers generally in the discussion have overlooked one of the most important points in the machine; I think without it we should not have had the Parsons turbine at all—I refer to the bearing. I think that Mr. Parsons' self-centreing bearing is enough to stamp a man an engineer, if he had never built a turbine at all. The Laval turbine has possibly been turned out in greater numbers than the Parsons turbine (I have no maker's data for either), but I believe, speaking generally, that is so. But the Laval turbine has its limitations, partially due to its having to make up for the self-centreing by using a flexible shaft. With his turbine Mr. Parsons got over the difficulty by making that very beautiful bearing, and so escaped the troubles that he would otherwise have found himself tied up with due to the variation in the centre of the long shaft. With regard to cooling towers, two or three speakers have Mr. Patchell.

Mr. Patchell.

mentioned temperatures, and the authors on p. 805, I think, apologise for the figures in one test through the cooling water being 85° F. I think it was Mr. Merz who said that we must use "proper" water. It all depends on what "proper" water is. If you have to depend on cooling-towers for your water, the neighbourhood of 80° F. is about the average temperature. If you put down natural draft cooling-towers you will find that is about the figure; if you put down forced draft cooling-towers you will find that when you have put a good deal of money into your fans and a good deal of energy into running them, the water is again at about the same figure; and I do not see, unless we can get better rivers in England providing us with our "proper" water, that we are to get the efficiencies out of the turbine that the makers have provided for us! I should be glad if they would give us further particulars of the vacuum augmentor. The few words that are stated about it in the paper lead one almost to believe that it is one of the paradoxes that are occasionally met with. Last week Colonel Crompton was talking about the efficiency of a boiler; he could not make out how it was better if he worked it in connection with the thermal storage tank. It looks like a paradox, but I believe it is purely a mechanical question connected with the circulation inside the boiler. Again, we get a great deal more benefit from using superheat in a steam engine, be it a turbine or a reciprocating engine, than the professors told us we ought to get, simply because they overlooked the question of leakage. If you have so many square inches or thousandths of square inches through which the leakage will take place, it makes all the difference in an hour's run whether it is steam or water getting through that void.

Mr. Mordey.

Mr. W. M. MORDEY: I do not think we ought to forget that when we went abroad last year we saw at Milan the 3,000 k.w. Parsons turbines made by Brown, Boveri & Co. Mr. Semenza said his experience of them was quite satisfactory. As compared with the Sulzer engines there his turbine plant took a quarter of the space had practically the same steam consumption, took less labour, and the turbine and alternator cost about the same as the reciprocating engine alone. The building work also cost less. I am sure we are all glad to hear of the experience of the enterprising head of the Chicago Edison undertaking. Engineering owes much to men like Mr. Insull, who had the courage to put in 5,000-k.w. turbines, and even to order three of them before they had tried one.

Mr. Lea

Mr. HENRY LEA (*communicated*): I first became acquainted with the Parsons steam turbine in the year 1895, when I induced some clients at Walsall to put down two 120-k.w. electric generating sets working with a boiler pressure of 120 lbs. per sq. in., and at that time non-condensing. They have been used ever since for driving and lighting a large wholesale clothing factory. The two machines cost £1,100, which at that time was about one-half the cost of a pair of reciprocating steam engine plants of equal power. They were not particularly economical in steam consumption, but, as in many such cases, steam consumption is not by any means the only consideration, and the difference in the price showed, at 5 per cent. interest, a saving of £55 per annum to be set against extra steam consumption. In the

year 1901 an independent condenser was added, with a water cooling-tower, which resulted in a large reduction in steam consumption. Only one of the two turbos is run at one time, and its day load in driving the factory is about one quarter full load. Only when the lighting comes on in addition to the driving is there anything like a full load. Accurate records of output and coal consumption are kept, and these show that the cost per unit is 1·33d, which includes coal at 10s. per ton, water, wages and repairs. Mr. Lea.

The point to which I think the greatest interest attaches is the cost of repairs to the turbos as steam engines apart from the dynamos. These repairs amount to £18 19s. 3d. for the nine years, or £2 2s. 2d. per annum, and of this £6 11s. 3d. was spent in taking the turbos down to examine them and putting them together again, the examination showing that there was nothing the matter, and that they need not have been dismantled.

Five years ago I put in two 120-k.w. turbo generating sets and one 75-k.w. set at a large asylum in North Staffordshire. These have been used for lighting the asylum, driving the laundry and the wood-working shop, and, recently, for driving an electric locomotive bringing coal and other supplies up a gradient of about 1 in 30, on an electric railway, about three-quarters of a mile long, with an overhead trolley wire. These machines are economical in steam consumption, but I regret that at the moment I cannot put my hands upon the exact figures.

The total cost of repairs for these three turbo generators during the five years they have been running amounts to about £3, or 12s. per annum, which represents repairs to the governing valves, nothing else having required any repair.

The simplicity and reliability of these machines in my view leaves little to be desired, and there is the great advantage of getting perfectly pure feed-water from the condensers without a trace of oil.

I am now putting in similar machines to another large asylum, and my past experience has led me to the conclusion that they are distinctly superior to any kind of reciprocating engine for such purposes.

The Hon. CHARLES A. PARSONS (*in reply*): Mr. President and gentlemen, I will ask Mr. Stoney, who became associated with Mr. Martin and myself in the development of the steam engine in 1887, and at a time when it was called by most people "a steam eater," to reply to the discussion, as he is probably more conversant with the later details than I am myself; but there are one or two points on which I should like to make a few remarks. In the electric lighting costs of stations to which Mr. Hammond has referred, oil, waste water, and stores are grouped together under one heading. As a matter of fact, the oil consumption is one of the very smallest items in the station costs with which I am acquainted. For instance, in the Newcastle and District Company, I believe the the station lamps are included under this heading, as well as various other items. Mr. Barker has just this minute handed to me a statement of the costs while he was in charge of the Cambridge station for nine years. The yearly cost of oil only was £40 per annum when they produced 300,000 units, which works out at ·003d. per unit. The oil used, as a Hon. Chas Parsons.

Hon. Chas. Parsons.

matter of fact, is from one-tenth to one-twelfth of that used by a reciprocating engine of the same power. Messrs. Brown & Boveri have gone very carefully into the costs of oil on the Continent, and they state that with the Sulzer engines, and other high-class engines on the Continent, it amounts to a saving of 12½ per cent. of the value of the coal bill over the reciprocating engine. I would like to allude to one other subject, namely, condensers. In the Newcastle and District Company's station about eight years ago, a large jet condenser was put in with the barometric head syphon for carrying away the injection water and water of condensation by gravity alone. Pumps were used to start the condenser, and to maintain the flow of water into the injection rose, and there were separate compound air-pumps for extracting the air; this condensing plant has given entire satisfaction, maintaining a vacuum of between 28 and 29 inches. It is a cheap form of condenser. The principle was not new when it was put in, and an account of a condenser with barometric head will be found in some of the old text-books.

Mr. Stoney.

Mr. Stoney (*in reply*): At the last meeting Mr. Sayers referred to the cutting of the blades by high velocity steam, but we have found that at the velocities which there are in the Parsons turbine there is no cutting, and many of the speakers have confirmed this from long experience. At the much higher velocities of steam in turbines of the single expansion form, say 3,500 to 4,000 feet per second, cutting undoubtedly takes place, and from experiments we have tried no material, even the hardest steel, is free from cutting. Mr. Sayers and other speakers referred to continuous-current dynamos. One speaker expressed the opinion that no dynamo was worth having unless it had carbon brushes. We must say that we beg to differ from him. We have tried many experiments with carbon brushes on turbine dynamos; they may run for a time, but sooner or later the high surface speed knocks them up, and also causes the commutator to heat. We have tried them both divided into numerous parts, and also large blocks, but none, so far as we can find at present, are as satisfactory as brass wire or gauze brushes. This is due both to the vibration and the chattering of the blocks, as well as the heating of the commutator. The speeds of commutators in turbine practice generally are from two to three times those in ordinary practice. With regard to our compensating winding, I would ask Mr. Sayers to note that we say "with improvements recently adopted." We regret that we are not at liberty at present to give details of this winding, but I may say that it is a modification of what Prof. Forbes proposed some years ago. Mr. Sayers' remarks with reference to Messrs. Jackson's experience at Ashton-under-Lyne are interesting, and we have also heard a good deal of the dynamos with Mr. Sayers' winding at the St. Helens Company in Lancashire. The great difficulty with these special windings, and also with those high-speed dynamos provided with compensating poles, as proposed by Ryan and others, and also with the Deri winding, is that the position where sparkless commutation is obtained is too defined. At no load it will be found that in an ordinary dynamo a considerable movement of the brushes can be obtained, and of course

Mr. Stoney.

that movement is not affected by any such thing as compensating winding or auxiliary poles, as there is no current passing round such compensating windings or auxiliary poles. At full load this movement is gradually diminished, until you come to a point where no movement of the brushes can be obtained without sparking. This is practically the sparking limit of the dynamo. If you keep your brushes within the limits given by the curves plotted of the possible movement of the brushes without sparking from no load to full load, you do not get sparking at any load. With our compensating winding we keep the same limits as an ordinary dynamo at no load, but at full load a rather larger range is obtained than is given by any other form of compensating winding which we have seen. With some forms of compensating winding and commutating poles that we have seen, you get sparkless commutation at no load, and also at full load, but sparking occurs at intermediate loads. This is caused by the inevitable errors due to differences of saturation, and so forth, not giving a right line law for the position of sparkless commutation. If you have what we call "soft commutation" as distinct from "knife-edge" commutation—knife-edge commutation is where you have to adjust your brushes as if they came up to a knife edge, absolutely accurate—if you have soft commutation you can obtain absolutely sparkless commutation at all loads. I think Mr. Hobart was the first to point out the great amount of induction in the coils of an armature caused by the end windings, but it does not seem to matter, to a certain degree, how much induction there is in the coils provided you have suitable compensating winding. If you only compensate for the induction, it obviously does not matter. Damping coils have often been suggested round magnet poles both by Deri, and also by Hobart. I think there are a large number of patents of various dates for damping coils, but they are both difficult to use in practice and also of very doubtful advantage. We have tried some experiments on that point, and cannot see any benefit in them.

In replying to Mr. Barker with regard to the vacuum augmentor, we do not think the same results could be obtained with any size of air-pump. The limit of what an air-pump will take out is soon reached, owing to the loss in the valves, and so forth, and owing to the enormous size of the air-pump necessary. It seems to us that some means, such as the vacuum augmentor we suggest, must be used. Reciprocating air-pumps and all forms of air-pumps become very uneconomical as soon as a high vacuum is required.*

Mr. Hammond observed that the only turbines he had put in are at the Hotel Cecil. Those are some of our early machines—I think they were made about 1894, and they are running still, and doing excellent work.

Mr. Hammond has spoken a good deal about oil consumption. I think Mr. Parsons has fully replied in regard to this, but I may say with regard to oil consumption that at Neptune Bank about a year ago they saved about £5 a week in oil by using the turbine instead of the

* Since writing the above we have been able to reduce the steam used by the augmentor from 450 to 270 lbs. per hour, or only about 1 per cent. in the case of a 1,500 k.w. plant, and we hope to be able to reduce it still further.

Mr. Stoney. reciprocating engines, and that corresponds to 2 lbs. per k.w. of steam consumption.

Mr. Hammond also doubts the possibility of maintaining 27 in. vacuum. I think Mr. Barker will say that at Cambridge, with the 150-k.w. machines he had there, he was able with jet condensers to maintain 29 in. vacuum over a long period of years; and it is the same in the Newcastle and District station. They have never had any difficulty in obtaining their vacuum; they have kept up a steady 28 in. to 29 in. vacuum year after year. It is a different thing where reciprocating engines are installed, and where there are numerous glands liable to leakage. It is also advisable not to exhaust the feed-pumps into the condenser. The proper place for these is the feed-water heater, which warms up the water for the economiser. If all these leaky reciprocating engines are turned into the condenser a bad vacuum is sure to be the result, and with average station management it is liable to go down in time. There is not the smallest difficulty, with proper precautions and reasonable care, in maintaining a good vacuum year after year.

With reference to the point that Table I. is given in different units from Table II., in order to enable them to be more readily compared the results are put in the same form as in Table II. in the following table :—

TESTS OF TWO 1,000 K.W. TURBO ALTERNATORS FOR ELBERFELD.

At Stop Valve.		Vacuum. Inches.	Speed. Revs. per Minute.	Load in K.W.	Steam Used per Hour.	
Pressure above Atmosphere. Lbs. per sq. in.	Superheat. F°.				Lbs.	Lbs. per K.W.
130	92	28·4	1493	1172·7	21,400	18·22
136	20	28·5	1461	994·8	20,040	20·15
130	18	28·2	1487	1190·1	23,160	19·43
140	14	28·4	1470	745·3	16,630	22·31
135	52	28·7	1473	498·7	12,520	25·2
131	31	28·5	1485	246·5	8,330	33·76
134	24	28·7	1488	0	4,065	—
136	24	28·9	1504	No exciting	2,607	—

Professor Dalby has very thoroughly given an exposition as to the advantages of a good vacuum. One of our difficulties in introducing the turbine has been to persuade people who are accustomed to reciprocating engines that a higher vacuum than 25 in. is beneficial, and we think at last they are beginning to see it.

Professor Dalby, in showing the advantage of good vacuum, demon-

Mr. Stoney.

strated that there is not so much to be gained by going to very high steam pressures. Our opinion is that 150 lbs. or 200 lbs. is quite high enough. We went into this question with Mr. Merz very carefully some time ago in connection with the Carville station, and concluded that even with machines as large as 4,000 k.w. there was no advantage in going higher than 200 lbs. The difficulty with steam pipes, valves, and everything else goes up very rapidly when very high steam pressures are reached. With turbines there is much more to be saved in the capital expenditure on boilers, in steam pipes, and in maintenance by moderate steam pressures than by going to very high pressures. If the cost of a station is worked out at 150 lbs. and 250 lbs., allowing perhaps not more than 2 per cent. gained in steam consumption due to the higher pressure and using a moderate amount of superheating of the steam, the gain in cost will be entirely on the side of the lower pressure. Most practical station engineers prefer the lower pressures. With reference to the pressures along a turbine, we may say that they agree with the theoretical curve, allowing for the efficiency of the turbine—that is, for the heat added by friction and losses in the blades, etc. We have calculated the pressures along our turbines, and compared them with the results of experiment, and as near as we can go they agree exactly.

Mr. Insull's account of the Chicago turbines is most interesting, and his practical demonstration that 30 per cent. is gained by the use of turbines is most satisfactory. I think the General Electric Company must certainly be congratulated on the way they have brought the Curtis turbine forward. Mr. Insull's figure that the cost of the turbine was only half that of the reciprocating engine in large sizes about agrees with our experience, and also that labour costs and miscellaneous expenses are only a fraction of the other. The increased cost of condenser plant is really only a minor item. With regard to the area of floor space used, I may mention that the area required by the Curtis turbine for a 5,000 k.w. machine and by a Parsons turbine of a similar size are identically the same in square feet. The Curtis turbine takes up a square; the Parsons takes up a rectangle, but the area is the same in both.

Mr. Dickinson spoke of the difficulty in maintaining a vacuum with surface condensers in the case of very bad water, and it seems under these circumstances jet condensers are often more satisfactory. They, with properly designed pumps, will take the worst water quite satisfactorily. To put against that, you do not have the condensed water to return to the boilers, which, in the case of the turbine, is suitable without filtration, as it is quite free from oil. In our works we use condensed water from steam turbines for delicate chemical work. At some breweries it is used for brewing in the vats.

Mr. Fox alluded to the counter current jet condenser and the barometric jet condenser. That has been in use for many years in the Newcastle district station with good results, and with no falling-off in vacuum. There is no objection to the condenser being at some little distance, if only large enough exhaust pipes are put in. Exhaust pipes can be got absolutely air-tight if properly made, either of

Mr. Stoney. galvanised iron or cast iron. These should have a good coat of thick red-lead paint, let them be well exposed to coal dust and dirt for a month or two, and they will be found to be absolutely tight. The best things for exhaust pipes are coal dust and dirt, the more the better.

I agree with Mr. Merz when he says that individual items cannot be taken, but only total costs. That is the most essential point. If a station is designed bearing in mind only the cost of one particular item, where would the other items be? I think there is no question that to Mr. Merz in this country, and to Mr. Insull in America, great credit must be given as being among the first to adopt really large turbines, and at the present in this country Mr. Merz has the largest turbine for a nominal maximum of 3,500 k.w. and an overload of 5,500 k.w. at the Newcastle-on-Tyne Electric Supply Company's station at Carville, which station has just been started in regular work.

Mr. Scott remarked about cooling towers with porcelain pipes. That is a very interesting suggestion, but I would like to see it worked out for perhaps a station with 10,000 k.w. in it. In a communication he has made he mentions the "steam blast" turbine. I presume he refers to the intermittent admission of steam by the governor, and this type, which is described on p. 807, is still used.

Mr. Leon Gaster's description of Messrs. Brown Boveri's work is most interesting. I have been out two or three times to Baden, and have seen their work there, and they are certainly doing most magnificent work in connection with the Parsons-Brown Boveri turbine. They were the first to get a 3,000-k.w. machine started at Frankfort, and the 6,500-k.w. machine for Essen is the largest steam turbine that has yet been built.

Mr. Cramp emphasised the fact that carbon brushes are very much overdone. My own belief is that carbon brushes have been chiefly brought in due to the defects of the common dynamo. If people had applied themselves to compensating winding and other methods, I do not believe the carbon brush would ever have obtained the prominence it has. It is most wasteful of power; electrically it is all wrong, and I think that its use will not be as great in the future as it has been in the past.

Prof. Ayrton spoke about the steam consumption of our turbines being maintained. It is only necessary to point to the consumption figures obtained by Mr. Merz after 16 months' use of the machines at Neptune Bank, and to Prof. Ewing's tests of a 500-k.w. at Cambridge after 12 months, which is given in our paper read at the Glasgow Conference. We have never, as has been pointed out by many speakers, had any wear on the blades, and there is no reason why it should occur.

Mr. Patchell spoke about the Laval turbine. De Laval has done a marvellous thing in producing his turbine, but it has limitations, since gearing cannot be made to stand satisfactorily over about 200 k.w., but it is a marvellous thing to think of the Laval disc some 76 centimetres, 30 inches in diameter, running at 10,000 revolutions a minute. It is a marvellous piece of work where you get velocities up to 1,400 feet per second in the disc.

Mr. Stoney.

With regard to Professor Ayrton's question about the comparatively small falling-off of the consumption of the Curtis turbine as the load is very much diminished, I may point out that our consumption for machines of these large sizes is considerably lower at full load. Take the average results of the Frankfort machine, as given on p. 799, you will see that the average result is much lower. If a turbine is used which adopts a cut-off, instead of throttling, you will undoubtedly get a lower consumption at very small loads; but it is, to a certain extent, at the expense of consumption at full load, as you will be able to see by comparing Prof. Ayrton's figures for the consumption of the Curtis turbines with the figures which Messrs. Brown Boveri have obtained with their Frankfort 3,000-k.w. machine, and which is only half the size of the Chicago turbine. It is not intended to operate engines of that size at quarter load; if such small power is wanted a smaller turbine should be put in, or if only very small powers, a reciprocating engine. For very small powers, probably under 100 k.w., it is admitted by everybody, including ourselves, that the reciprocator is the best in the point of steam consumption, though not for maintenance, oil consumption, attendance, etc.

The President.

The PRESIDENT: You have already by your applause given your thanks to the authors for their most excellent paper, so that it is unnecessary to propose a vote of thanks.

I have to announce that the scrutineers report the following candidates to have been duly elected:—

Member.

Charles F. De Nordwall.

Associate Members.

Beaumont Pontifex.
William Shearer.
James E. Starkie.
Charles A. Taylor.
John T. Walton.

Students.

Robert L. Beamish.
John Duckworth.
Herbert S. Ellis.
Charles G. E. Gradisky.
Henry C. Greenwood.
Stanley Henderson.
William Johnson.
Philip H. Morgan.
Wilfrid Robson.
Leonard Van Vestraut.

REPORT OF THE COMMITTEE ON TRACTION, LIGHT, AND POWER DISTRIBUTION ON THE VISIT OF THE INSTITUTION TO ITALY IN 1903.

The chief feature in the Italian tour which differentiates it from the preceding tour in Germany is that the object was generally a generating station, railway, or some accomplished work rather than a manufactory. As there is no predominant Italian firm, and therefore no standard practice, we saw a great variety within a comparatively small area.

At MORBEGNO a water-driven generating station was supplying three-phase current at 20,000 volts for a railway which is worked with three-phase, 3,000-volt motors.

At TORNAVENTO we saw a steam-driven three-phase, 13,000-volt generating station supplying power to sub-stations, where it is converted into continuous current for use on the Milan-Varese Railway at 600 volts.

At VIZZOLA we saw a water-driven generating station supplying three-phase current at 11,000 volts for distribution over a large area to 2,400 industrial consumers, whose working pressures vary from 3,600 volts down to 125 volts.

At PADERNO we saw a water-driven generating station supplying three-phase, 13,000-volt current principally to Milan, where the supply is supplemented by steam-driven plant consisting of turbines and horizontal engines.

We were much impressed with the enterprise, foresight, and practicability shown throughout; money has been spent lavishly but not recklessly. Very perfect and up-to-date hydraulic works have been built on a scale that, considering the country's resources, is very striking. Canals have been cut, weirs built for the equipment of the power stations, and capital seems to have been always forthcoming whenever the scheme has shown practical signs of paying. Although money has been spent on works of this nature without stint, it should be noted that the Italians show their business capacity by not sinking their capital in heavy underground mains, more particularly between urban districts, but use overhead wires carried on wooden poles, so that 10,000 h.p. may be transmitted at the cost of about £800 a mile, instead of ten times this figure if underground mains were adopted.

We learn that no accidents have occurred through the overhead wires, even with a pressure as high as 20,000 volts, during the last two years; and there appears to be no precaution taken to prevent unauthorised persons climbing the posts, except a small circlet of iron spikes. Such a thing as a casualty through a wire breaking has not been heard of.

We do not propose giving details of the various plants we saw, as much has already been published in the technical press, and Professor Carus-Wilson's Paper on the Italian Railways,* forms a useful introduction to those works.

* *I.E.E. Journal*, vol. xxxi. p. 1091.

The plants we saw aggregated some 60,000 h.p., about two-thirds of which were driven by water. The governing in these is generally done by oil under pressure, which actuates a piston suitably connected to pivoted guide blades, the movement of which regulates the amount of water passed through the turbine.

In steam-driven sets it was interesting to find two Parsons steam turbines of 4,500 and 3,000 h.p. respectively among the fine examples of horizontal engines by Franco Tosi and Sulzer Bros.

The generators presented nothing specially novel, and the periodicity, as usual, covers a wide range; at Valtellina it is 15, and at Vizzola 50.

The exciters at Morbegno are on the main turbine and generator shaft, but have their fields excited by a small set driven by a separate turbine, as better regulation is effected thereby.

The switchboard work is particularly fine. The gradual substitution of automatic circuit breakers in place of fuses was noticed.

At Paderno oil switches are used, and provision is made whereby each feeder can, if necessary, be run on a separate machine.

At Porta Volta a new switchboard is being built in concrete; each 'bus-bar, switch, fuse, etc., has a compartment to itself, and the switches are so arranged that they can be run out of their compartments on rails.

It is unusual to find, as at Morbegno, a dummy load used for synchronising, as this is rather a relic of bygone days.

The overhead distribution systems were most interesting; the insulators appear to be very simple, considering the high pressures they have to carry.

The insulators on the Paderno-Milan line are a special feature, introduced by Mr. Semenza, of the Italian Edison Company. He uses an insulator built up of three parts, which, after being tested separately, are cemented together with litharge and glycerine. Better insulation is obtained by this method of manufacture than when insulators of the ordinary type are used, and in practice they have proved entirely satisfactory.

The lightning arresters were generally of the Wirt type, consisting of a horn gap in series with a spark gap condenser and resistance. At Morbegno these had not been altogether successful when used alone, and a most interesting form of water-discharger has been adopted. Three jets of water, about 10 inches long by ½ an inch in diameter, are played from a well-earthed pipe into inverted metal saucers, one of which is connected to each line. Although the pressure is 20,000 volts, we are told that their resistance allows discharge of static electricity to earth, but presents a path of such high resistance that the current from the line passes only in comparatively negligible quantity. The leakage is said to be about one-tenth ampere per phase.

Storage batteries are largely used. In the Milan scheme, in addition to a buffer battery on the traction system, there are four batteries each of 5,000 ampere-hours' capacity at a 1-hour rate. They are arranged two in parallel on each side of the middle wire, with 260 volts across the "outers." There are no regulating cells, but each battery

has a Thury booster in series with it, the fields of which are automatically regulated on the Magrini system.

The static transformers seen were generally of the three-limb type, with primaries and secondaries wound on alternate coils, and are cooled by air blast. Near Paderno a sub-station is working, with a pressure automatically regulated by a large impedance coil on the secondary side of a transformer.

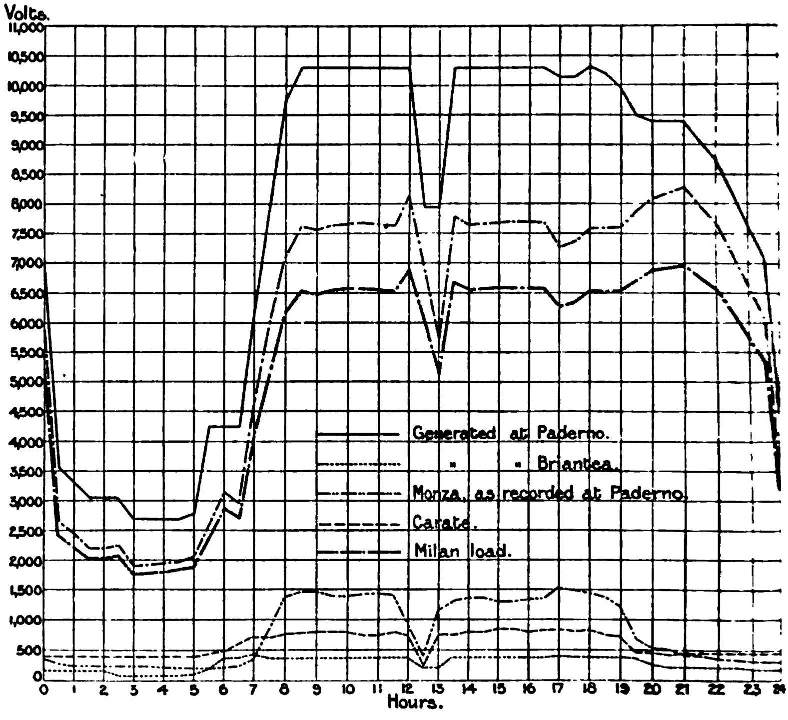

Chart I.

Rotary transformers are in use in connection with the railway work, but in Milan we found motor generators in favour, where they are used both of the synchronous and induction type.

Milan Charts

The accompanying charts show the power supplied by Paderno on December 3, 1902, to Milan, showing a maximum of 10,300 kilowatts. Of this the outlying towns absorbed about one quarter, as indicated by the curves at the foot of Chart I. Chart II. shows how the peak of the load is carried by the steam auxiliary, then by the batteries on the lighting and power circuits. As the load diminishes, the batteries begin to charge. Chart III. shows the distribution of the actual load

at Porta Volta into current for trams, lighting (by continuous current), and on the three-phase network.

RAILWAYS.—On the three-phase railways the two working conductors at 3,000 volts are independently supported at a height of 20 feet from the rails in the open and 16 feet in the tunnels; this construction allows a higher insulation than when the usual method of supporting two conductors on the one system of overhead wires is employed.

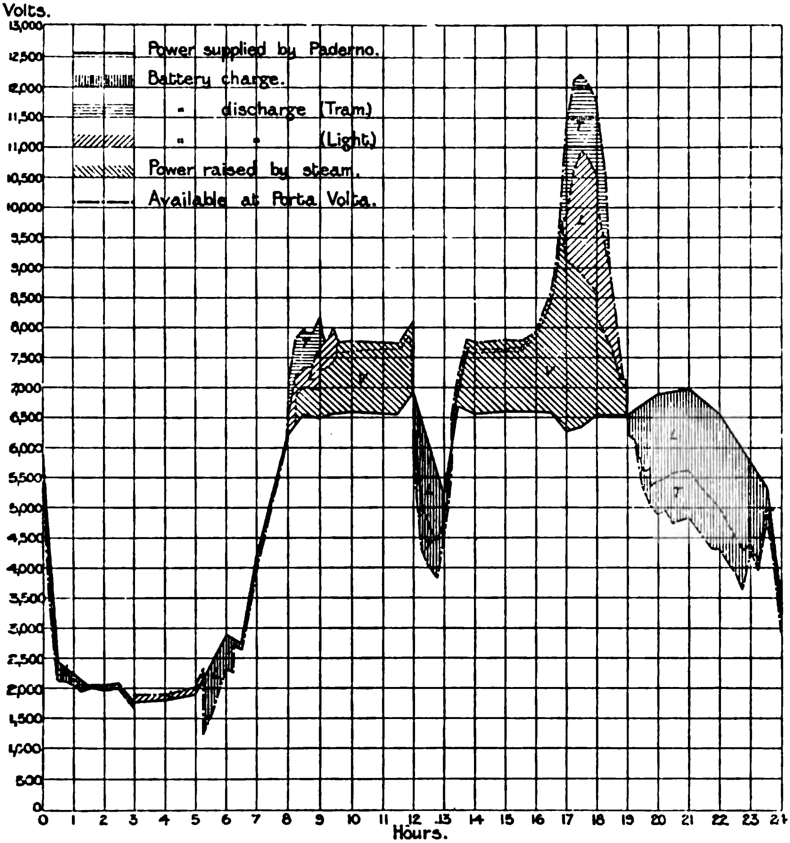

CHART II.

Double insulation is provided between each line and earth by means of Ambroin insulators for the trolley ears, and porcelain strain insulators near the poles. Two trolleys are used on each car, with phosphor-bronze rollers, 26 inches by $3\frac{1}{4}$ inches, on a creosoted wood rod, separated by an insulating piece of about 10 inches. They run on ball bearings. Ten motor cars are in service; the ordinary carriages, which were previously used on the line, are retained and used as trailers. Each motor car has four six-pole, 150 h.p. Ganz motors, with the necessary switches and

controlling mechanism. Liquid rheostats regulate the current to the motors, the plates being fixed, and the liquid (carbonate of soda) forced in, to immerse them more or less, by compressed air under the control of the driver. The trolley is moved into contact with the overhead wires by means of compressed air, to obviate any danger to the employés, and very careful regulations had been made to protect them, with the result that only one or two accidents have occurred, and those

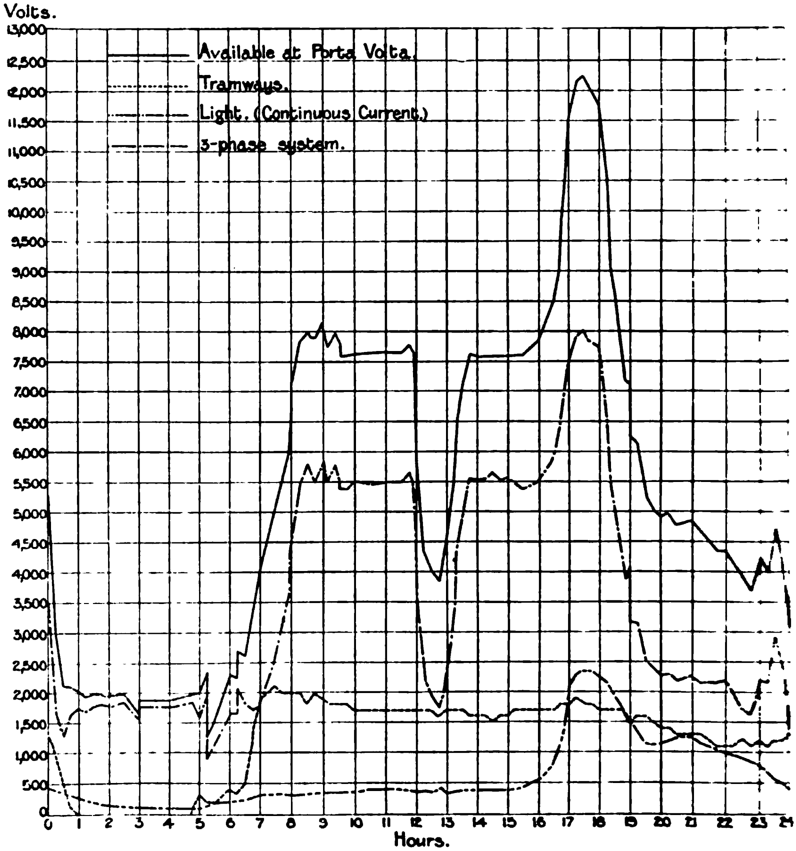

CHART III.

were the result of great carelessness. So far as the public are concerned no accident has occurred.

The Milan to Varese line is the usual third-rail type. The third rail is supported every 15 feet by artificial granite insulation in cast-iron holders bolted to the sleepers; flexible copper bonds are used. Twenty motor cars are in service and sixteen more are in hand. Each car has four general electric motors of 165 h.p., and a controller at each end, as well as an air-brake and hand-brake. Twenty trailers of the ordinary

type of cars used on this railway are to be included in the rolling stock. There is also one electric locomotive of thirty-five tons, which also has four 165 h.p. motors.

The speeds attained on this railway are much higher than those on the Valtellina line, as no question of frequency limits the service, and over fifty miles an hour is easily accomplished. The current used is from 500 to 700 amperes, or up to about 600 h.p.

We take this opportunity of thanking the various Italian engineers for the information embodied in above report, and also have to particularly thank our reporters—Mr. W. H. Donner, Mr. A. H. Foyster, Mr. R. S. Portheim, and Mr. J. T. Morris.

We may also mention that the illustrated handbook prepared by Mr. Semenza, printed in Italian and English, which was handed to all the members who took part in the trip, is to be found in the library of the Institution.

REPORT OF THE COMMITTEE ON TELEGRAPHS AND TELEPHONES ON THE VISIT OF THE INSTITUTION TO ITALY IN 1903.

TELEGRAPHS.

At the Central Telegraph Station at Milan, it was observed that typewriting instruments working on the Hughes and Baudot systems were very largely in use, minor circuits being served by Morse apparatus.

A new telegraph office was in course of erection, so that although up-to-date methods were in use, many of the more modern electrical fittings in the existing building were designedly of a somewhat make-shift character, it being intended, of course, that the new office, when opened, should be provided with the most modern appliances.

One point of considerable interest to the electrical industry is that the overhead transmission of the electrical energy used on the Adriatica Railway had caused such disturbance in telegraph circuits skirting the line as to render it imperative to convert them into metallic loops. In order, however, to obviate the necessity for providing metallic loops throughout the whole length of the circuits, repeater stations have been placed at each end of the railway line, and the cost of these stations and of the clerks necessary for working them has been borne by the Railway Company. Probably the inductive trouble has arisen owing to the unsymmetrical manner, from the inductive point of view, in which the wires, both main and trolley, were erected. It was observed on the Varese line that the overhead three-phase wires were erected so as to revolve in the same manner as telephone circuits do in this country, and under these conditions the effect on the neighbouring telegraph and telephone circuits was so much less marked than on the Adriatica line that no special steps had been found necessary to maintain working in a fairly satisfactory manner.

TELEPHONES.

In Italy the telephone trunk lines are in the hands of the State, but the local telephone exchange service and the connecting junction lines in certain defined areas are controlled by two companies, the Alta Italia, dealing with Northern Italy, and the General Italian Company, dealing with Central and Southern Italy, although it was gathered that these two companies are in close touch with one another.

In Milan absolutely new plant had been provided, as the introduction of electrical traction had rendered the working of the old single wire lines utterly impracticable. Lead covered multiple telephone cables had been laid underground throughout the City, and a new horizontal switchboard of the Siemens and Halske type had been installed at the central station. A brief description of this board was given in a paper on the Paris Exhibition, page 85, Vol. 30. The internal plant was well designed, well constructed, and very compact, and the switchboard appears to be well adapted for an installation of the type at Milan, where practically the whole of the subscribers are concentrated at one exchange. Under this system, the duty of the telephone operator is restricted to learning the requirements of the calling subscriber and joining him through to his correspondent, if the latter's line is free. The caller then has to ring up his correspondent, and this has one advantage, it keeps a very energetic man busy, and if the correspondent delays his answer the irritated caller visits his wrath on the right party, and not on the unfortunate telephone operator. This system does not, however, work satisfactorily where a local area is so large as to involve the erection and maintenance of a considerable number of exchanges.

At Milan there are 125 subscribers per operator, and the number of conversations average seven per subscriber.

I noticed that the numerous power circuits in Milan caused scarcely any disturbance on the local telephone circuits, little more than a slight musical note being observed on those I tried.

The rates are very moderate; they vary from £6 8s. for an ordinary user to £8 for a busy one, both being flat rates. The area to be served, however, is limited and this is the great factor which determines telephone rates.

NEWCASTLE LOCAL SECTION.

THE DISTRIBUTION OF ELECTRICITY IN SHIPYARDS AND ENGINE WORKS.

By J. A. ANDERSON, Associate Member.

(*Paper read at Meeting of Section, January* 18, 1904.)

In submitting a paper to this meeting the writer has chosen the title "Distribution of Electricity in Shipyards and Engine Works" on the assumption that the day has gone by when a comparison of electricity with steam or gas motive power in engine works and shipyards possesses debatable ground or even interest. Before a meeting of Electrical Engineers, and in a neighbourhood where more has been done in the direction of power distribution than elsewhere in this country, such a comparison is unnecessary. On the other hand, the writer hopes that a description of the different means of applying electricity which he has met with as an engineer engaged in power distribution, and especially the figures he has been able to obtain, may prove acceptable and possibly provoke discussion.

The first consideration in designing a distribution system for an engine works and shipyard is the choice of system to be adopted (1) for power, (2) for lighting. Some engineers advocate three-phase and others direct current throughout. The writer is, however, strongly of opinion that a combination of the two systems--namely, three-phase for power and direct-current three-wire for lighting—(and, in special cases, power)—possesses the greatest advantage.

Distribution from a power company is invariably on the three-phase system, and at first sight it would appear that three-phase should therefore be used throughout, but where there is a large motor load as well as lighting, it is preferable to have both systems. The motor load on the three-phase system does not affect the lighting load off the direct-current system—a most important consideration. This arrangement admits of a large momentary demand on the power side, and three-phase motors of 10 H.P. and under can be started up direct off the mains. The voltage drop does not appreciably affect the speed of the motor-generators for the direct-current supply, so that the lighting is unaffected.

Three-phase motors are much more cheaply maintained and stand overload to a much greater extent and length of time than direct-current motors, and hence in many cases a smaller motor can be used than would be possible on a direct-current system. To get the full advantage of electric driving in engine works, however, direct current should be available for driving a few variable-speed machines.

As most of my data is in connection with three-phase motors, a short description of the two types in general use with their respective advantages and disadvantages may not be amiss:

1. Those with a squirrel-cage or short-circuited rotor, started by

means of a compensator which reduces the voltage at the terminals of the motor, the transformer portion being cut out by means of a throw-over switch when the motor has attained maximum speed. Compensators usually have three separate sets of connections, designed as a rule to give 80 per cent., 60 per cent., and 40 per cent. of the line voltage. I will in future refer to this motor as the squirrel-cage motor.

2. Those with a drum-wound rotor. Three ends of the winding are connected to slip-rings on the spindle and the other three ends are "star" connected. Resistances are inserted between the armature winding by means of the slip-rings when starting. These resistances can either be cut out by a controller, which also operates the primary circuit, or by a regulating switch, with a triple-pole switch for the primary. I will in future refer to this motor as the slip-ring motor.

The chief difference between the squirrel-cage motor and the slip-ring motor is the starting current. The squirrel-cage motor takes about 2½ times full-load current for full-load torque at starting, whereas the slip-ring motor gives about full-load torque when taking full-load current. The slip-ring motor is from 10 per cent. (for the larger sizes) to 20 per cent. dearer than the squirrel-cage motor, and the latter type is a little more efficient and less complicated.

For ordinary use, therefore, the squirrel-cage motor is the better, although it has to be very heavily fused if started up against a load as is necessary in many cases in shipyards. It requires, however, much less attention, and the wiring is not so complicated and expensive. The last reason is sufficient to debar slip-ring motors for use on such machines as punches, shears, and beam benders, where the starting gear has sometimes to be placed at a considerable distance from the motor. For such machines as winches and cranes, the slip-ring motor is the only one which will prove satisfactory. The Newcastle Electric Supply Company have now out on hire over 40 three-ton shipyard winches driven by 10-H.P. motors of the slip-ring type, and they are entirely successful from every point of view, especially from the point of view of economy.

The figures below, taken from one of the above winches, show

K.W.	Volts.	Amps.	P.F.	Remarks.
3·5	442	7·8	·6	Winch running light.
5·1	440	8·9	·75	Running with weight on brake lever.
8·4	—	17	—	Starting on first step of controller.
7	436	11	·84	Running with increased weight on lever.
8·6	—	16	—	Controller on first step would not start without slight assistance.
11·2	—	20	—	Starting on second step of controller.
9·5	436	14·5	·87	Running with increased weight on lever.
12·6	—	22	—	Starting on second step of controller.
10·2	436	15·8	·86	Running with increased weight on lever.
12·8	—	21	—	Controller on second step, but would not start without assistance.
16·2	—	—	—	Starting on third step of controller.

the kilowatts taken in starting various loads. Weights were placed on the foot brake lever as an artificial load, and the motor started up by a controller. The figures clearly show the low demand from the mains when starting in proportion to the load.

A winch was tried fitted with a 10-H.P. squirrel-cage motor, but it could only lift about 15 cwt. unless started with a slack rope, even when switching the motor direct on to the mains.

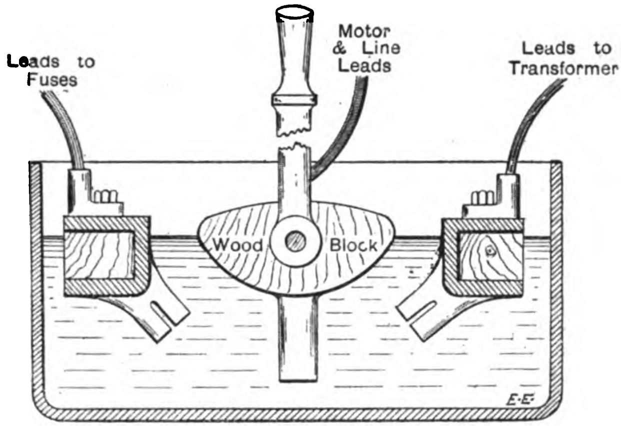

FIG. 1.

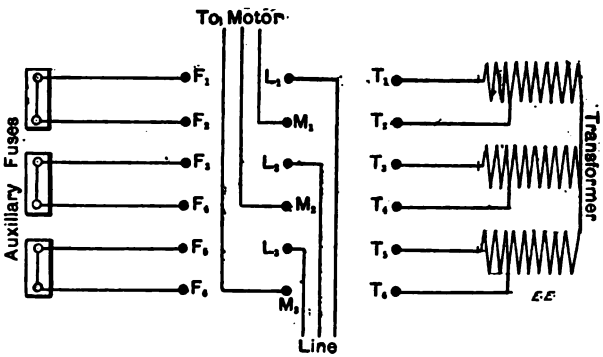

FIG. 2.

For ordinary use the squirrel-cage motor has so many distinct advantages over the slip-ring type, that it is well worth going to some extra expense to adopt an arrangement for placing lighter fuses in circuit when running. Figs. 1 and 2 show an arrangement which the writer has had in use for some months.

Fig. 1 is a diagrammatic sketch and Fig. 2 is a section through the oil-break switch of a 10-H.P. starting compensator, the split terminals of which were modified to suit. Originally the split terminals, F_1

and F_2, F_3 and F_4, and F_5 and F_6, were short-circuited, so that when the switch was thrown over to that side the motor was direct on to the line. These double terminals have been replaced by six single terminals, making both sides similar in this respect, and F_1, F_3, and F_5 are connected to F_2, F_4, and F_6 respectively through auxiliary fuses. The knife-blade terminals, M_1, M_2, M_3, L_1, L_2, and L_3, are mounted on a wood block, to which is connected the switch handle. At starting the switch is thrown over to the transformer side with the usual transforming effect. After the motor has got up full speed the switch is thrown over to the running side, and puts the auxiliary fuses in circuit. The ordinary motor fuses are placed at the distributing point in the usual way. This starting gear was first connected to a 10-H.P. motor driving a large punching and shearing machine which was exceptionally hard to start up, the slides being out of order. The compensator had to be connected up on the highest step, and the current through the ordinary fuses at starting was about 80 amperes, the motor taking 44 seconds to get up to speed. With the above arrangement we were enabled to run with auxiliary fuses of 22 S.W.G. copper in series with the 18 S.W.G. copper necessary for starting.

The writer has now got this gear connected to a 10-H.P. motor driving a small machine shop at Carville power station, where the starting and running conditions are not so severe, and we have been enabled to run with 26 S.W.G. copper auxiliary fuses. The above switch would be greatly improved if a spring were attached, so that the switch could not be left in the starting position. It will be seen from the diagram that by merely short-circuiting the transformer terminals and cutting out the transformer it is possible to start direct off the mains.

Having briefly described the two main types of three-phase motors, I now propose to consider the conditions under which they are set to work, and the arrangements it is necessary to make for their installation. Most of the machines in a shipyard should be separately driven. They have as a rule to be spaced far apart, which would increase the amount of shafting required to drive them in groups, and they have also to work very intermittently.

The following figures taken from a shipyard shed, and until last January driven by a 50-N.H.P. Crossley gas-engine through a friction clutch, illustrate the amount of power wasted in driving shafting. Most of the shafting has been done away with and squirrel-cage motors installed, with very beneficial results.

Gas-Engine.

Period of Test, February 16 to August 16, 1902.

Total gas consumption = 1,380,500 cubic feet at 2s. 6d. per 1,000, less 20 per cent. = ...	£138	1	0
Man in attendance	48	0	0
Water	4	11	0
Oil and stores	5	0	0
Total...	£195	12	0

The average daily gas consumption was about 8,320 cubic feet, and the average indicated horse-power about 62. Of this the indicated horse-power required to drive the main and counter shafting was about 40. The attendance expenses above do not include cleaning and repairs beyond the ordinary cleaning and oiling allowance daily.

Three-Phase Motors.

Period of Test, February 16 to August 16, 1903.

	Motors.	Horse-power.
Six punching and shearing machines, with a $7\frac{1}{2}$-H.P. motor on each	6 ...	45
One 27 ft. by $1\frac{1}{8}$ in. plate rolls	1 ...	30
One scarfing machine and plate-edge planer ...	1 ...	10
" " " ...	1 ...	10
One 6 ft. 6 in. by 1 in. straightening roll, two countersinks, and one grindstone	1 ...	10
Two countersinking machines	1 ...	5
Total	11	110

Units consumed = 32,916 at $1\frac{1}{16}$d. = £145 14s.

In this case no man was required, the starting and stopping being done by the machine men, so that the saving effected equals £195 12s. less £145 14s., or £49 18s. per half-year. The maintenance and other charges on the extra capital is more than counterbalanced by the upkeep on the shafting and belts and overhauling the gas-engine, not previously taken into account. The system of driving is such that practically all machines are stopped when not required to work, the saving being wholly effected by this. On a full day's work the costs of running as taken above are about the same for both systems.

Punching and shearing machines can best be driven by belt from the roof principals or from the top of the machine itself, although this latter position sometimes gives too short a drive. Quadruple punching and shearing machines with an overhead jib crane can only be driven with the motor underground; the use of a guide pulley is also necessary, making a very unsatisfactory drive. Driving such machines by gearing throws very heavy stresses on the motor, which are more or less avoided by using a belt. Belting is also more often than not much cheaper.

In one case plate rolls are driven by a 40-H.P. slip-ring motor with heavy resistances in the rotor circuit for speed regulation. The motor is geared to the rolls and reversed by the controller. When the rolls are under way the reversing current is very excessive: for this reason the fuses have practically to be short-circuited. A foot brake has been tried to stop the machine before reversing, so as to reduce the rush of current, but it has not been successful. In a boiler shop the plate rolls are driven by a similar motor, but by means of a countershaft and crossed belts for reversing purposes. This arrangement, where possible, is to be preferred, as it saves the momentum in the rotor and there are

no heavy spur wheels to reverse. Although speed regulation of the motor is, perhaps, more satisfactory, it has been found to be practically unnecessary, as the operator can get what regulation is required by allowing the crossed and open belts to slip, but I do not think that the advantage is worth the extra expense incurred by using this type of motor. In another shipyard the rolls are driven by a 30-H.P. squirrel-cage motor by means of a countershaft with crossed and open belts. Although the rolls are lighter than the rolls previously mentioned, they do the same class of work, and are, on the whole, more satisfactorily driven.

In engine works, where sometimes direct-current motors are essential, separate mains should be run from the sub-station, but these motors should be as few as possible, and connected across the outers of a three-wire system. They are claimed to be of most benefit when driving variable-speed machines, such as lathes, drilling machines, and boring mills, as they do away with belting. This is not altogether an advantage, for, as is well known, the belt forms an elastic coupling between the motor and its load, and thus, if a sudden stress comes on the machine, the belt slips and may save the motor and gearing from injury.

In engine works the current consumption is not much reduced by separate driving, for, as a rule, the machines are all running simultaneously, and not intermittently as in a shipyard. On the other hand, a great advantage is gained by being able to space the machines independently of the shafting, but as this benefit is greatest for large machines, separate motors for machines requiring 5 H.P. and over, and driving all the others from shafting, would seem a good arrangement. Among the former, one or two lathes might be driven by direct-current motors when a constant speed regulation is a great advantage, but other variable-speed machines, such as boring mills and drilling machines, when the amount of work done at one speed is considerable, might just as well be driven by three-phase motors with belts and stepped cone pulleys.

In reconstructed shops, where some other motive power has been displaced, it is best to cut up the shafting into sections according to the nature of the shop, and at the same time do away with as much belting and shafting as is justified by the cost.

For driving large cranes in constant use, it has been proved that three direct-current motors give the best efficiency, but the first consideration should not be efficiency, but reliability and freedom from breakdown. The use of three direct-current motors with commutators, controllers, resistances, and complicated wiring all tend to increase the possibility of breakdown. On the other hand, a single three-phase squirrel-cage motor crane has very few electrical connections, a starting compensator displaces three controllers, magnetic brake, and heavy resistances with their respective connections. The three-phase type necessitates the use of a square shaft and friction clutches for the longitudinal traverse on the crane itself, but these require much less skilled attention than the direct-current motors with their connections and accessories, and the capital cost is also less. My experience with

three direct-current motor cranes has, perhaps, been unfortunate, but, notwithstanding, I think the above points worth consideration.

Some engineers advocate the use of three-phase slip-ring motor cranes where three-phase current only is obtainable, but the high efficiency gained by the three direct-current motor crane is no longer obtainable, due to the inefficiency of the motors when running with a heavy resistance in the rotor circuit, and at the same time the connections are more complicated, and the system necessitates the use of 11 trolley wires between the crane girders.

The following figures taken from a few of the three-phase motors connected to the Newcastle Electric Supply Company's system will, I think, help to support some of my remarks and suggestions :—

5-H.P. Squirrel-Cage Motor 800 Revolutions, driving Two Countersinking Machines by Belt and Countershaft.

Work done.	K.W.	Remarks.
Shaft and countersinks running light	2·7	—
One head countersinking $\frac{3}{4}$ in. holes in $\frac{5}{8}$ in. plate ...	2·8	Minimum.
" " " " " ...	4·8	Maximum.
Two heads " " " " ...	2·8	Minimum.
" " " " " ...	7·4	Maximum.

$7\frac{1}{2}$-H.P. Squirrel-Cage Motor, 800 Revolutions, driving Punch and Shear by Belt on Flywheel. 27 Punches per Minute.

Work done.	K.W.	Remarks.
Running machine light	3·1	—
Punching $\frac{3}{4}$ in. holes in $\frac{5}{8}$ in. plate	3·8	Minimum.
" " "	5·4	Maximum.
Shearing $\frac{1}{2}$ in. plate	7·4	—
" "	8·8	Average.
" "	9·4	—
Shearing $\frac{3}{8}$ in. plate 21 ft. long	5·4	—
" " "	8	Average.
" " "	11	Operation took 1 min. 20 sec.
Shearing $\frac{3}{8}$ in. plate 21 ft. long, cut about 3 in. wide	5·6	—
" " "	9	Operation took 1 min. 10 sec.

In shearing, the load varies with the width of cut as well as the thickness. Some figures taken from another machine, shearing 1 in. plate, 2 in. to 3 in. width of cut, show a $7\frac{1}{2}$-H.P. motor taking from 6 k.w. to 12 k.w.

$7\frac{1}{2}$-H.P. Squirrel-Cage Motor, 800 Revolutions, driving Mast Rolls by Countershaft and Open and Crossed Belts.

Work done.	K.W.
Countershafting and loose pulleys	2·8
Rolls running light	3·3
Rolling $\frac{4}{10}$ in. plate to half circle	4 to
" " "	7

$7\frac{1}{2}$-H.P. SQUIRREL-CAGE MOTOR, 800 Revolutions, driving a Double-Headed Boiler-Shell Drilling Machine by Belt and Countershaft.

Work done.	K.W.	Remarks.
Drills running light	2·6	—
Drilling one $1\frac{3}{16}$ in. hole in boiler shell	3·5	—
" " " "	3·8	—
Drilling two $1\frac{3}{16}$ in. holes in boiler shell	4·5	—
" " " "	5	—
Drilling one $1\frac{5}{8}$ in. hole in $1\frac{1}{4}$ in plate	4·5	Sharp drill.
" " " "	4·7	Operation took 1 min. 40 sec.
Drilling one $1\frac{5}{8}$ in. hole in $1\frac{7}{16}$ in. plate	4·6	Blunt drill.
" " " "	5	Operation took 2 min. 5 sec.
Drilling two $1\frac{5}{8}$ in. holes in $1\frac{1}{4}$ in. plate	6·7	Sharp drill.
" " " "	7·7	—

$7\frac{1}{2}$-H.P. SQUIRREL-CAGE MOTOR, 800 Revolutions, driving Brick Crusher.

Work done.	K.W.
Crusher running light	2·8
Crushing bricks	3
" "	6
" "	8

$7\frac{1}{2}$-H.P. SQUIRREL-CAGE MOTOR, 800 Revolutions, driving a Buck and Hickman Mortar Mill with a Revolving Pan, 7 ft. Diameter, 16 Revolutions per Minute, by Countershaft and Loose Pulley.

Work done.	K.W.
Countershaft and loose pulley	2·4
Running mill with pan empty	4·4
Mixing with pan full	7·6
" " 5 minutes after	6·8
" " 15 "	6·4
" " 24 "	6·4

$7\frac{1}{2}$-H.P. SQUIRREL-CAGE MOTOR, 800 Revolutions, driving "Koppel" Concrete Mixer by Countershaft and Loose Pulley.

Work done.	K.W.
Running on loose pulley	2·1
Machine running empty	2·6
Hoisting tub filled with ballast and cement	5·2
Mixing with cylinder charged	3·8
" " "	4·0
" " "	4·4

10-H.P. SQUIRREL-CAGE MOTOR, 800 Revolutions, driving Two-Headed Scarfing Machine and a Plate-Edge Planing Machine by Belt driving a Countershaft with Loose Pulleys, Crossed and Open Belts.

Work done.	K.W.	Remarks.
Countershaft and loose pulleys	4·7	—
One-head scarfing cut $\frac{5}{8}$ in. to $\frac{1}{8}$ in. by 9 in. long	5·2	Minimum.
" " " ...	7·8	Maximum.
Planing $\frac{5}{8}$ in. plate 20 ft. long	9·2	—
" " "	13	Average.
" " "	16	—
Planing $\frac{17}{32}$ in. plate 20 ft. long and scarfing $\frac{17}{32}$ in. plate	10	—
Planing $\frac{17}{32}$ in. plate 20 ft. long and scarfing $\frac{17}{32}$ in. plate	13	—
Planing $\frac{17}{32}$ in. plate 20 ft. long and scarfing $\frac{17}{32}$ in. plate	16	—
Planing $\frac{17}{32}$ in. plate 20 ft. long and scarfing $\frac{17}{32}$ in. plate	18	Maximum for five seconds.

The above motor, although very often considerably overloaded, runs very satisfactorily and does not get too hot.

10-H.P. Slip-Ring Motor, 800 Revolutions, driving Angle-Iron Planer by Worm, Worm-Wheel, and Gearing. Speed controlled and rotation reversed by controller.

Work done.	K.W.
Planing 10 in. channel iron cut $\frac{5}{8}$ in. × $\frac{1}{16}$ in.	3·8
" " " "	4·8
" " " "	5·8
" " " "	6·6
Planing 4 in. angle-iron cut $\frac{7}{16}$ × $\frac{1}{16}$ to $\frac{1}{8}$ in.	6
" " " "	6·8
" " " "	7
" " " "	8

10-H.P. Squirrel-Cage Motor, 800 Revolutions, driving Quadruple Punching and Shearing Machine by Belt Motor Underground.

Work done.	K.W.
Machine running light	2·4
Shearing $\frac{5}{8}$ in. steel plate	12
" " "	13·2
Shearing $\frac{3}{4}$ in. steel plate	13·2
" " "	14·4
Punching $\frac{7}{8}$ in. holes in above $\frac{3}{4}$ in. plate	13·2
" " " "	14·4
Punching 4 in. holes in above $\frac{3}{4}$ in. plate, $\frac{7}{8}$ in. holes previously punched round the circumference	10·8
Punching 4 in. holes in above $\frac{3}{4}$ in. plate, $\frac{7}{8}$ in. holes previously punched round the circumference	12

All the above readings were taken with the belt slipping very badly.

Belt dressing was put on, and the following readings taken:

Shearing $\frac{3}{4}$ in. steel plate as above...	14
" " "	16

Work done.	K.W.
Punching 4 in. holes in ¾ in. steel plate as previously	16
" " " " "	18
" " " " "	20·8*

This machine had very light flywheels, and the steel plates were for some special purpose not often required in ordinary shipyard use. The plate was fed in as fast as possible for the purpose of taking the test.

10-H.P. SQUIRREL-CAGE MOTOR, 800 Revolutions, driving Four Small Planing Machines, Three Small Shaping Machines, Three Slotting Machines, and Two Screwing Lathes by 95 ft. of 3 in. Shafting running at 175 Revolutions per Minute, and driving Six Countershafts.

Work done.	K.W.	Remarks.
Shafting and belt running light	4·8	—
Ordinary working	5·6	Readings taken at various dates.
" "	6·6	—
" "	8	—
" "	9	—
" "	10	Average.
" "	12·2	—
" "	14·4	Occasionally.

10-H.P. SQUIRREL-CAGE MOTOR, 800 Revolutions, driving 6 cwt. Pilkington Hammer and a Fan for Two Smiths' Fires.

Work done.	K.W.
Shafting, fan, and loose pulley on hammer	3·6
Hammer cushioning	8
Hammer working	11
" "	13

15-H.P. SQUIRREL-CAGE MOTOR, 600 Revolutions, driving Mangles, Scarfing Machine and Operating Gear for Lifting Large Rolls by Shafting and Belts.

Work done.	K.W.
Shafting and loose pulleys	6·4
Scarfing machine cutting light	8
" " " "	9·4
Mangling ⅝ in. plate	12
" "	14
" "	16
Reversing with plate in time 6 sec....	30
Heaving large rolls	15
Scarfing, mangling, and heaving rolls simultaneously	21

During this last operation the belt came off, and the motor was being lifted off its bed. The motor was then replaced by a 20-H.P.,

* Motor slowed up.

and is working satisfactorily, but I consider it would be worth installing separate motors for each machine—5-H.P. for scarfing and 10-H.P. on each of the other machines.

15-H.P. Squirrel-Cage Motor, 800 Revolutions, driving a Manhole Punch by Gearing.

Work done.	K.W.
Machine running light	3·2
Punching 24 in. × 18 in. manholes in $\frac{7}{10}$ in. plate	19·6
" " " "	21·2
" " " "	22·4

This machine punches heavier plates satisfactorily, although I have not had the opportunity of taking observations when doing so. The time taken for each operation was about five seconds.

30-H.P. Squirrel-Cage Motor, 480 Revolutions, driving 27 ft. by $1\frac{1}{8}$ in. Plate Rolls by Belt on to Countershaft with Crossed and Open Belts.

Work done.	K.W.	Remarks.
Rolls running light	11·4	—
Lifting top roll	14·4	—
Lowering top roll	11·6	—
Rolling $\frac{1}{2}$ in. plate	12·8	—
" "	14·4	—
" "	40·0	Momentary.
Straightening $\frac{5}{8}$ in. plate	13·4	—

I have not had the opportunity of getting readings from this machine when rolling $1\frac{1}{8}$ in. plate, but the 30-H.P. motor has proved adequate. With bending and straightening rolls the amount of load is almost entirely in the hands of the operator, and is to a great extent independent of the size of plate.

30-H.P. Slip-Ring Motor, driving Joggling Machine by Gearing, with the Speed varied and Rotation reversed by a Controller with Heavy Resistances in the Rotor Circuit.

Work done.	K.W.
Joggler running light	4
Joggling $\frac{1}{2}$ in. plate at 5 ft. 9 in. per minute	5·2
" " " "	5·6
" $\frac{13}{20}$ in. " "	7·6
" " " "	8·4
" " " "	10
" $\frac{15}{20}$ in. " "	11
" " " "	12
" " " "	14

As will be seen from the above figures, a much smaller motor would be sufficient. I should say a 20-H.P. motor would be large enough to joggle plates up to 1 in. thick at the above speed.

30-H.P. MOTOR, 480 Revolutions, driving One Large Horizontal Boring Mill, One Large Vertical Boring Mill, One 10 ft. Chuck Lathe, One 30 ft. Shaft Lathe, 14 Lathes (Various Sizes), and Two Drilling Machines by 160 ft. of 3½ in. and 70 ft. of 2¾ in. Shaft at 150 Revolutions per Minute, with Countershaft for each Machine.

Work done.	K.W.	Remarks.
Large chuck lathe cutting light	17	All others off.
30 ft. shaft lathe running light, chuck lathe cutting light, and vertical boring mill cutting out propeller boss	20	Ordinary working.
Chuck lathe cutting light, 30 ft. shaft lathe cutting off centres, vertical boring mill cutting out crank webs	21	,, ,,
,, ,, ,, ...	24	,, ,,
,, ,, ,, ...	25	,, ,,
,, ,, ,, ...	26	,, ,,
,, ,, ,, ...	30	,, ,,
All machines working except a few small lathes and horizontal boring mill. Large vertical boring mill drilling 5½ in. hole in a shaft coupling	26	,, ,,
,, ,, ,, ...	28	,, ,,
,, ,, ,, ...	31·2	,, ,,
Same as above, only with large drill off ...	20	,, ,,
,, ,, ,, ...	22	,, ,,
,, ,, ,, ...	23·2	,, ,,

Mr Stoney. Mr. G. G. STONEY: We should feel very much indebted to Mr. Anderson for his interesting and useful contribution. It contains a good deal of work—chiefly statistical—and raises the question as to which is the best method for the distribution of electricity in factories, workshops and other places. Whether it should be a three-phase, continuous, or single-phase alternating, is a debatable question. It is as puzzling to electrical engineers, as the correct mode of mixing concrete to civil engineers. I was once present at a discussion as to the best method of mixing concrete, but in the end we were as far from a definite conclusion as when we started; nevertheless, we learnt a great deal about mixing concrete.

The chief difficulty with three-phase current is with cranes and variable-speed motors. Speaking generally, we have to remember that we create alternating current in a dynamo and transform it into continuous by a commutator, and then at the motor again alter it into alternating. This double transformation is obviously wasteful, and the more direct way is to use the alternating current entirely as alternating without any transformation into continuous.

Mr. Riseley. Mr. H. L. RISELEY: With regard to Mr. Stoney's remarks about the mixing of concrete, why not do it by electricity? There are machines of this kind at Carville and New Bridge Street which are working most satisfactorily and require no attention.

Mr. Riseley.

I agree with Mr. Anderson, and think that there is no comparison between three-phase and direct-current motors. In a direct-current motor, there is, when unskilled labour is employed, the fear of burning out resistances. I know of three-phase motors being used for outside work which require no attention at all. Up to 20 H.P., it is only necessary to put in a three-pole switch, and anybody can start the machine. The previous speaker remarked upon the great amount of energy which is absorbed in the shafting. As a matter of fact, manufacturers do not seem to realise the amount of money they are spending in driving shafting. In one instance which has come under my notice there was a 3-H.P. motor at one end and it required a 20 H.P. to drive the shafting. It is difficult to explain to manufacturers how much the shafting does absorb.

I would like to mention that the North Eastern Marine Engineering Co., after three years' experience with direct current, are going in for three-phase machinery.

Mr. Holmes.

Mr. JOHN H. HOLMES: We are all in search of data based upon practical experience, which will enable one to judge the power required by different kinds of machines. The figures given in the paper should be useful in that way. The paper covers a very wide area, and there are many points to be discussed. At the bottom of p. 846, in speaking of electrical winches, I think it a pity that Mr. Anderson did not make his experiments on winches when lifting definite loads, when other and more useful data would have been obtained, rather than by weighting the footbrake lever as was done. The table as it stands is almost valueless.

I have often remarked that a belt was the best form of friction clutch invented. It answers most admirably in cases of this kind. People have gone to a great deal of trouble to invent friction clutches which are by no means as satisfactory as a belt.

With regard to direct-current motors, I cannot agree with the author's remarks. It seems to me, for many cases, that the direct-current motor has many great advantages over any multiphase motor which has practically a uniform speed. In the case of cranes, for example, one advantage of the series-wound motor is that with light loads, quicker lifting is obtained, which seems a reasonable way of going about the work. In the case of machine tools, say for drilling, a direct-current motor, series-wound, will run fast when drilling small holes as it ought to do, so as to give practically the proper speed for the work in hand. When drilling large holes the motor will slow down automatically to again giving practically the proper speed.

On page 851, the author mentions that the load varies with the width of the cut as well as the thickness. Does that mean that, when shearing an inch off a plate, the machine takes less current than when shearing 2 inches?

Lower down in the paper I notice that there is not much difference in the amount of the current used with the various drills. Perhaps there is a difference in the thickness of the plate. With regard to what Mr. Riseley says about burning out resistances, I have not had much experience of multiphase machines, but I have come across cases

Mr. Holmes. where resistances have been burnt out. It seems to me that resistances could be burnt out in starting up, just as readily as in a direct-current machine. With regard to friction driving, I think that it might be more used than it is. In the early days of electric lighting, I had considerable experience of dynamos driven by friction from the fly-wheel of a steam engine. I have also seen layers of paper very much compressed, used for friction driving when the power was transmitted very satisfactorily. I think great results might be obtained by the use of these paper pulleys, but the expense might militate against them.

Mr. Proctor. Mr. C. F. PROCTOR: I would like to have Mr. Anderson's opinion on starting three-phase motors. From the little experience I have had, it would seem that they gave a great deal of trouble when first started with load. Another point Mr. Anderson brings up, is the enormous loss by friction. I would like to know if Mr. Anderson has had any experience of roller bearings. In ordinary factory work it can be seen whether the coal bill is getting greater or smaller, and where it is used, and in the same way, by watching the current consumed, it should be possible to see how much is used for useful work, and how much for friction. The next point is the price of current. Is $1\frac{1}{16}$d. the usual rate for electricity? Can this be counted upon as a general price for driving? I would also like to ask if the author has had any experience of friction-driving, such as leather-covered against a metal pulley, or two metal pulleys together, and whether the drills referred to were twist drills or the ordinary flat type.

Mr. Head. Mr. W. J. HEAD: I fully agree with Mr. Holmes as to the three-phase motor resistances being more easily burnt out than those for continuous-current motors. Mr. Riseley had probably used the wrong sized resistance for his continuous-current motor referred to. I know of one case of a three-phase motor of 30 B.H.P. having had the standard 30-H.P. resistance burnt out, and it was found necessary to put in a 60-H.P. resistance to carry the necessary current. I think efficiency should be one of the first considerations, most proprietors of large works taking this view, but Mr. Anderson has practically treated this as a negligible quantity.

The paper implies that speeds are not required to be variable in shipyards, but this is really not the case; take, for instance, frame and angle punching machines where there is often light and heavy work to contend with, and for which a continuous-current motor will be found more suitable.

Then again, one cannot group machines in a shipyard as in an ordinary workshop, when probably three-phase motors would not be so much out of place if grouping were desired.

With regard to three-phase motors carrying 100 per cent. overload, this is not very wonderful, and I know of a direct-current machine of 5 B.H.P. which, on an emergency, was capable of working to 15 B.H.P. for a quarter of an hour; since it was put in it has never had a piece of sandpaper on the commutator, nor the brushes renewed.

I would also like to refer to Mr. Williamson's able paper given before the Institution in May last, which although not bearing directly upon the subject of three-phase motors, throws many side-lights on

the question of the greater adaptability of the continuous-current motor. Mr. Head.

I believe that, in many of the larger shipyards, where the motors are numerous, it would, on the point of economy and adaptability, pay to put in rotary converters when they had a three-phase supply to deal with.

I visited some works in the north recently where there was a very large three-phase installation. They also had a large motor running of about 130 B.H.P., the speed of which was required to be variable and I was surprised to find the amount of gear required to obtain this result; in fact, they had erected a house to take it, and needed a man to look after it. I thought at first it was a transformer station, but I was informed that it was simply the starting gear and resistance required to obtain the variable speeds. It might have cost something approaching the value of the motor itself. Direct-current motors will and do run without attention if properly designed, so that three-phase motors cannot hold a monopoly in this respect.

Mr. L. E. BUCKELL: I would like to draw the attention of two or three of the later speakers to the great point of the paper, namely, the use of squirrel-cage motors. Anybody admits that resistances are just as likely to be burnt out in the three-phase as in the direct-current machine, but these are not required with squirrel-cage motors. The last speaker referred to Mr. Williamson's paper, but at the beginning of his paper he pointed out that his scheme was laid out three years back, and I have very little doubt that Mr. Williamson would have done it in a different way to-day. I agree with Mr. Anderson that it is more important for large works to keep their machinery going than to have 5 per cent. or even 15 per cent. extra efficiency. Mr. Buckell.

Mr. J. MCFALL: About three years ago I had the fitting up of the Burnley Iron Works in Lancashire, where they had a number of machines, planers, punchers, slotters, lathes, and all the necessary machinery in an ironworks. They fitted a dynamo which took 150 H.P. off the engine that was running. They put small motors to several machines in the place, all of which were direct-current. At the moment I cannot give the actual figures of the results, but I would be pleased to procure them for any member who wished to see them. These machines have been running for the past two and a half years most satisfactorily, and beyond an occasional breakdown, they have had no difficulty whatever, and I do not see any reason why direct-current motors could not hold their own against three-phase. Mr. McFall.

While not disputing the point in the paper with regard to squirrel-cage machines, I notice there are no particulars given *re* slip-ring machines. It would be interesting to have figures taken one against the other in the different positions.

Mr. GEO. RALPH: With regard to three-phase motors, is there any trouble experienced due to wear in the bearings? The clearances are so small that any decentralising of the rotor must mean a very heavy pull towards the side of least clearance. Mr. Ralph.

Mr. Anderson speaks of driving plate rolls by a constantly running motor with open and crossed belts. I suggest that a flywheel on the

Mr. Ralph. motor shaft would effect a considerable saving of current at the moments of reversal. I have found the use of flywheels of great advantage in this respect in driving hoists, planing machines, etc. Mr. Anderson states that the abolition of belts is claimed to be one of the important advantages in coupling continuous-current motors direct to boring mills, etc. Personally, I agree with him that the elasticity of a belt drive is an advantage, but I imagine that there are few practical users of variable-speed motors who look on the abolition of the belt as an important point to be considered. It is the fact of being able to vary the speed instantly and easily which makes the direct-current motor so very much superior for driving this class of machine tool.

In the next paragraph the author alludes to lathes driven by direct-current motors where *constant*-speed regulation is a great advantage. I imagine this is a slip or misprint, *variable* speed being meant. I cannot agree with the further remark that other variable-speed machines, such as boring machines, might just as well be driven by a constant-speed three-phase motor. I hold very strongly to the opinion that easily variable speed is *the* chief advantage of electric driving for many classes of machine tools. In support of this I may mention that many of the leading machine tool makers in this country and in the United States are devising and supplying mechanical speed variators to attain the same object, namely, to enable the operator to get many more speeds than are possible with stepped cones. One eminent firm of lathe makers in this country is at the present time selling off cheap their stock of ordinary lathes because they have recently patented and put on the market a variable speed drive without any stepped cones, which they consider so great an advance over previous practice that they have abandoned the manufacture of the stepped-cone class.

Mr. Bigland Mr. H. H. BIGLAND: Personally, I quite appreciate the self-sacrifice involved, knowing full well the time required in preparing so many details.

Anything which I say to-night is by no means with the desire "to go for" the author, but with the object of securing facts and real comparisons, both of which are too frequently neglected at many of these meetings.

This is not the first time I have raised my voice here on behalf of the gas engine as against the electric motor. I do not do so from any "interested motives," in fact, quite the reverse, but I do think it has been the practice of many members to blacken the character of the gas engine needlessly, and in opposition to actual facts and existing circumstances—all of which in the long run will tell against the progress of electrical undertakings.

The figures given by the author on pages 848 and 849 seem to me to be such that on the face of them there is something very far wrong, and I have been to the trouble of analysing carefully the statement.

(1) *As regards the gas consumption.* The number of days from February 16th to July 16th inclusive, without taking into consideration the off-time for Race week and Easter holidays, is 126. Taking these at 9 hours per working day, this gives 1,134 hours, which if multiplied by the average I.H.P., as stated in the paper, gives 70,308 H.P.-hours

during the time of the test (1902 months, yard full swing; 1903, slack). The first point which is to be considered is the condition of the gas engine during the test, and this may be found by calculating the gas consumption per I.H.P. per hour; therefore, if the quantity of gas used is divided, 1,380,500 cub. ft. by 70,308, the consumption of gas is found to be 19·6 cub. ft. per I.H.P. per hour. This at once shows that the engine was not properly looked after, and was not in anything like a condition to work economically, as with coal gas of 630 B.T.U.'s the consumption per I.H.P. should not have been more than 13·5 cub. ft., therefore the quantity of gas used is 31·1 per cent. too much. Correcting the figures accordingly, the cost of gas should have been, roughly, £95 instead of £138. As a matter of fact I believe the time value of the engine allowed a consumption of 4 cub. ft. per I.H.P. per hour more. Mr. Bigland

(2) As regards the question of wages, it seems to me that the man in attendance on this engine must have had very little work to do. To say that a man is paid something like £2 5s. per week for attending a gas engine is absolutely ridiculous, and does not reflect very much credit on the management. I suggest that 5s. per day is ample for any such class of labour, and if on to this is allowed one half day per week, the wages would amount to £35 12s. 6d.

(3) Regarding water, oils, and stores I do not intend dwelling upon these, but at the same time the water does seem a heavy item. In addition to this there must be taken into consideration the question of capital expenditure. I find that the cost of an engine of this class is about £550, to which add £200 for shafting—which I take to be ample under almost any conditions. If, say, 5 per cent. is allowed for interest on capital, 5 per cent. for depreciation, 5 per cent. for repairs and maintenance, the figure arrived at, for the five months covered by the paper, is £46 17s. 1d.

If all those figures are tabulated it will be found that the cost of running the gas engine should not have been more than :—

Cost of gas	£95	0	0
Wages	35	12	6
Water	4	11	0
Oil and stores	5	0	0
Interest on capital expenditure	46	17	1
	£187	0	7

To turn to the electrical side of the question in this estimate, there s no allowance for attention at all, and it is only a pity that the whole f the observations have not extended for a more lengthened period han that under review. It is known well enough that workmen if arefully supervised will be careful in switching off the motors when ot required. It is also a well-known fact that workmen, unless so upervised, will *not* go to the trouble of switching off the motor on very occasion, and I have no doubt the author will agree with me on his point. It seems to me, therefore, that during the period of the

Mr. Bigland. experiment something *should* have been allowed for supervision, but as the author has not made any allowance for this I propose also to leave it alone. I notice there is no allowance made for oil. Possibly the motors may be of some new type, running without oil, and so I will not consider the oil.

The next question is, What is the *capital expenditure* on the motors installed? A rough estimate of the amount would probably be something like £1,200 (£1,150 to £1,250). The interest on this, on the same basis as that taken in connection with the capital expenditure of the gas plant for the five months will be £75, therefore if these are summarised it is found that the cost of current at $1\frac{1}{18}$d. is :—

	£145	14	0
Interest on capital expenditure	75	0	0
	£220	14	0

As already stated, the cost of gas running is £187 0s. 7d., and, therefore the balance in favour of gas for the five months is £33 13s. 3d.

From what has been said it may be inferred that great carelessness *or* want of knowledge has been shown in the running of the engine and the compilation of the figures by the parties who supplied them to the author. That some carelessness or want of knowledge is no doubt responsible for the fact that 64·5 per cent. of the power is wasted in the shaft running light.

I suggest that in the first place the main-engine drive was bad. It probably was a very short drive. This, of course, is never an economical drive, especially with a belt of the weight necessary to develope the maximum power of the engine named, the necessary tightness of the belt causing a heavy friction on the bearings, not only of the shafting, but of the engine. Had this been in order a further 20 per cent. might have been put in in favour of gas engines. Much more might be said on this point, but I think my remarks have been extensive enough to enable me to formulate the opinion :—

(1) That the party responsible for the gas drive, cannot by his performance consider himself entitled to rank as an ornament to the profession of engineering.

(2) That so far as management is concerned there has practically been none.

(3) That the figures given reflect the carelessness or bias displayed in the whole of the work.

Mr. Snell. Mr. J. F. C. SNELL: I think that the tests which I have been making in Sunderland for the past eighteen months might be interesting. In one case the figures should be taken with a grain of salt, as I am speaking from memory. To show the amount of loss which takes place in counter shafting, I have had some tests made in a saw-mill. The owners put in a 50-H.P. motor, and no less than 22 per cent. was lost in driving counter shafting. Had the owners, instead of putting in one large motor, split up the power into several small motors, they would

have had higher efficiency. One thing which people seem to overlook is the increase in speed and therefore increased output of the tools. To my mind this is an important factor. I have had some interesting tests made in three different shipyards, one of which drove the whole of the plant electrically, but the prime movers were gas engines. In that case the cost per unit actually worked out at 1·33d. delivered from the engine-room. In another case, where a number of gas engines were used for driving dynamos and distributing to motors, the cost worked out at 0·98d. I do not agree that the consumption of an average gas engine is 13·5 cub. ft. per hour. I know of a test of a gas engine, by well-known makers, taken in the presence of a gas engineer, which worked out at 37 cub. ft. per k.w. hour. I am not for a moment going to decry our opponent the gas engine, which, in many cases, has a good future before it, though I am of the opinion that the electric motor has a better future. One may get a test of 15 cub. ft. from a gas engine on first being installed, but after it has been in use for some time the consumption goes up very considerably. If a great deal of money were spent in keeping the machine in repair it would possibly keep the consumption down. Mr. Snell.

One firm in Sunderland has replaced its gas engines by motors, with the result that there is an increase of speed and therefore of output, and also a considerable saving of floor-space. There is no question that in shipyards, where there are isolated winches, shearing machines, punches, riveters, etc., electric motors are the best prime movers. It is impossible to plant a gas engine in the middle of a shipyard, whereas a motor can be placed in almost any position.

Mr. C. TURNBULL suggested that a separate transformer might be used for lighting purposes instead of a motor generator, as this would save the lights from being affected by the heavy currents needed for starting up motors. The transformers might be controlled by a small automatic regulator, such as are now commonly used, and this would keep the voltage steady even if the primary voltage varied. Mr. Turnbull.

Mr. G. VARDY: I did not think that any question would arise as to the efficiency of electrical driving in shipyards or engine works. In every case where there is an installation the question answers itself. There are still one or two mechanical devices, however, which are difficult to drive by electricity, for instance, hydraulic pumps, etc. Mr. Vardy.

In the case of air compressors, where it is necessary to work economically, we ought to be able to vary the speed more. There should be an arrangement for slowing down the speed of the compressor to very considerable limits. Mr. Anderson may know of some such arrangement.

The question of three-phase and direct-current machines to pure electricians is a question of the efficiency of motors, but to mechanical men, like myself, the question is the efficiency of the works. Three-phase answers better for some parts of the works than direct current—in addition to being simpler in starting. Any ordinary workman, after being shown once, finds no difficulty in starting and stopping the machines. In my experience there appears to be no great difficulty in three-phase work so far as engine works are concerned. I have seen

Mr. Vardy. lathes which have been working for the last two to three years with a variable speed arrangement. The motor has a continuous speed, yet there is a variation of speed in the tool. This is a self-acting arrangement with the number of revolutions increasing as the tool nears the centre.

The question of single- or three-phase motor cranes seems to me more a question for the man who has to use them. If a crane has to transport stuff about a shop over long distances, it must have a high speed, though it is of no use having a crane going faster than a man could travel.

In the case of a boiler, engine, or erecting shop, a single motor crane is a distinct advantage, and where the distance is not great it is also an advantage. It is a question of distance and speed. The cranes work efficiently through a friction clutch. The direct-current cranes have not given us any trouble, they probably have good motors.

Mr. Unwin. Mr. P. I. UNWIN: I do not think there could be a better object lesson on the use of electricity in shipyards and engine works than the remarks we have just had from Mr. Vardy. In the Tyneside shipyards financial arrangements are very carefully watched, and any waste observed without delay, and more economical methods adopted wherever possible. One speaker gave 1·33d. per unit as the cost of generating power by gas engines. This is probably correct, but in reply I should like to say that electricity can be obtained for power purposes in Newcastle at very considerably less than 1·33d. per unit. Shafting losses are a very serious matter, often 50 to 60 per cent., and these can be almost entirely saved by the use of electric power. In a certain case of which we have recent experience the losses in shafting were most serious, owing to a slight want of alignment, and this had been going on unsuspected for some considerable time, until discovered by the application of an electric motor to the line shafting, and proper methods of measuring the power used. Another argument against the use of gas engines is the fact that the consumption of gas rises considerably with the age of the engine, and that, being a more complicated machine, it requires more labour, more attention, more stores, and more repairs than the electric motor.

I hope I have said sufficient to prove that in nearly all cases where power is readily available, electric motors can be more economically applied than gas engines.

Mr. Anderson. Mr. J. A. ANDERSON (*in reply*): I wish to thank the various members for the very interesting discussion on the points raised. I regret that some of the motor readings are incomplete in many respects, but they were taken in the ordinary course of business, and were not then intended for publication. The figures from the winch, to which Mr. Holmes drew attention, were taken with a view to finding the starting current required at various loads. I regret that I have not yet had an opportunity of obtaining figures from these winches when lifting definite loads. I have never seen a series-wound motor attached to a drilling machine in the manner described by Mr. Holmes, but I think it would be very difficult to arrange the speed to suit the various-sized drills without having an adjustable resistance in circuit. With regard

Mr. Anderson.

to the remarks of various members in reference to the burning out of resistances on D.C. and T.P. motors, I think this matter is only a question of design, and depends on the work the motor has to do. Resistances for three-phase motors are heavier than for D.C. motors, but, on the other hand, they are not subject to such a high voltage. It is certainly best to do without them wherever possible, and to use squirrel-cage motors. In reply to Mr. Proctor, although three-phase motors take a heavy starting current they give no trouble, and, as mentioned in the paper, possible bad effect may be easily overcome by inserting auxiliary fuses. Many examples could be cited of motors running under considerable overload, but the question is all a matter of rating. Three-phase motors are certainly better adapted than D.C. motors for peaky loads such as those in shipyards. To equip a shipyard with D.C. motors costs about fifty per cent. more than with three-phase motors, and this is surely sufficient argument apart from any other consideration. There is no doubt whatever that D.C. motors are better adapted for running at variable speed, and where this type of load is prevalent I would advise a D.C. installation throughout; but the drawbacks to a variable-speed three-phase motor are after all not so great as to absolutely debar its use. In fact I have reason to know that three-phase winches are much cheaper to maintain than D.C. winches. Although I expected trouble with three-phase motors, due to the small clearance between rotor and stator, I have not yet experienced any. I agree with Mr. Ralph that fly-wheels might be used with advantage on such machines as plate rolls when driven by open and crossed belts. Three-phase motors could be used with advantage on lathes if a variable-speed gear such as Mr. Ralph and Mr. Vardy suggest were brought into use. Messrs. Lang, of Glasgow, make such a gear, but I have not yet seen it in use. Mr. Snell mentioned a case where 22 per cent. of the power was lost in shafting, but this is by no means an exceptional case, 40 to 50 per cent. loss being a common amount in engine works, and 60 to 70 per cent. in shipyards. The question of driving hydraulic pumps raised by Mr. Vardy is one of great importance. For a plant of large output I would suggest running one set of pumps continually, and arrange a bye-pass valve to be opened by the accumulator when it reaches the top. Another set of pumps could be arranged to start and stop automatically at certain positions of the accumulator. I much regret that a slip occurred in the statement with regard to the duration of the tests on the gas engine and motors. The tests were for six months between 16th February and 16th August in each year. This has misled Mr. Bigland considerably, but at the same time he could have arrived at the approximate gas consumption per I.H.P. hour by taking as a basis the average daily gas consumption of 8,320 cubic feet. Assuming, as he did, an average of [illegible] hours per day, and the average I.H.P. as 62, the consumption equals about 15 cubic feet per I.H.P. hour. This is a fair figure considering the amount of time the gas engine would be running considerably under full load. The man's wage was taken from his time-sheets, and it is not considered excessive. Mr. Bigland draws attention to the oil for the motors. This is only a matter of about £1 10s. per half-year, and is

Mr. Anderson.

included in the Newcastle-upon-Tyne Electric Supply Company's upkeep, particulars of which I am not at liberty to produce, but, as stated in the paper, the amount is more than counterbalanced by the upkeep on shafting, belts and gas engine. I cannot agree with Mr. Bigland that 5 per cent. is enough to allow for the maintenance of shafting, belts, and gas engine. I quite agree that, as Mr. Stoney points out, there is a great deal to be said in favour of gas engines, and that they can be used in many cases with advantage, but I am sure that these cases are all outside shipyards and engine works.

DUBLIN LOCAL SECTION.

STEAM TURBINES.

By F. C. PORTE, Associate Member.

(Abstract of a Paper read before a Meeting of the Section on Feb. 11, 1904.)

The first authentic record of the use of steam as a motive power dates back to the second century before Christ, when the great Egyptian philosopher, Hero of Alexandria, described a primitive steam turbine in his work on Pneumatics. This turbine consisted of a hollow sphere mounted on two bearings, one of which was hollow for the purpose of admitting steam into the sphere. The steam escaped from two pipes fixed at opposite sides of the equator, which were bent tangentially so that the steam issuing from the open ends of the pipes produced a backward reaction which caused the sphere to rotate.

Nothing further seems to have been done in this direction from the time of Hero until the 14th century, when it is reported that some mechanics made a turbine on similar lines. From that time, again, till the year 1629 there is another long blank. In this year, however, there was made in France a turbine in which a jet of steam from a boiler impinged on a wheel and drove it round. During the remainder of the 17th and also during the 18th century many people were working at the problem, till Watt invented the steam engine practically as we know it to-day, in which the steam acted on a piston, and through the medium of a crank imparted a rotary motion to a wheel. The steam engine for a time quite eclipsed the turbine, and nothing of any real value was done till De Laval invented his first turbine in the year 1882.

The Parsons turbine was first made by the Hon. C. A. Parsons in 1884, and was of the reaction type. It has undergone many great improvements until it is now made as large as any steam engine in the world, and has about the same efficiency as the best reciprocating engines.

THE DE LAVAL TURBINE.

De Laval's first turbine was constructed for the direct driving of milk separators, and worked much on the same principle as Hero's. The driving wheel was a pipe bent in the shape of the capital letter **S**, to which the steam was admitted through a stuffing box in the centre, where the shaft was also fixed. The steam issued from the open ends, thus imparting to it a rotary motion. This turbine was mounted on the same shaft as the separators, and on account of the high speed and small space occupied it was most suitable for the purpose. Many of these separators are still at work in all parts of this country; but on account of its high speed and wasteful steam consumption, in addition

to the fact that it required considerable attention, it was not made in large sizes. As now constructed, the De Laval turbine is founded on the action or impulse principle. The steam blows from stationary nozzles against vanes or buckets fixed round the periphery of a wheel, thus driving the wheel round, much on the same principle as a jet waterwheel. There is only one row of buckets on the De Laval turbine, and the steam in passing this row delivers up a large portion of its energy, and is then exhausted either to atmosphere or to a condenser. The principle will be easily understood from Fig. 1, which is a perspective view of the wheel showing the nozzles, one of the nozzles being shown transparent so that the steam can be seen passing through it and impinging on the buckets.

As in the case of all action turbines, whether water or steam, the working depends on the kinetic energy of the medium which drives it, and the greater the kinetic energy, the greater the power to be derived from it. It is therefore important that the driving medium should have the greatest possible kinetic energy; or in our case, that every pound of

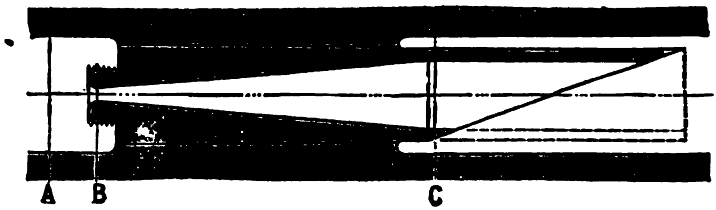

FIG. 2.—Sections of Nozzle.

steam passing through the nozzle, or nozzles, should enter the wheel at the highest possible velocity, and also that the greatest possible amount of the kinetic energy of this steam should be utilised by the vanes of the wheel for the purpose of imparting motion to it. In this turbine a high velocity of steam is obtained by passing it through specially adapted and constructed conical nozzles, in which the steam is expanded from its original pressure down to that of the case in which the turbine revolves.

A section of a nozzle is shown drawn to scale in Fig. 2. This nozzle is intended for a 200-lb. boiler pressure and a vacuum of 28 in.; which means the steam is expanded in the nozzle from 215 lbs. absolute down to 0·93 lbs. absolute, and this expansion gives the steam which leaves the nozzle a very high velocity of outflow. Extensive calculations have been made, and experiments have proved that if the steam is expanded adiabatically in the nozzle, all the potential energy of the steam is converted into kinetic energy, and the energy of this steam is absolutely the same as if the steam was expanded in the same proportion in the cylinder of an engine. With an initial pressure of 200 lbs. per sq. inch above atmosphere and 28-in. vacuum, supposing the steam to be dry—that is, that it does not contain any moisture—then at the line A the pressure is 200 lbs. per sq. inch above atmosphere, the percentage of

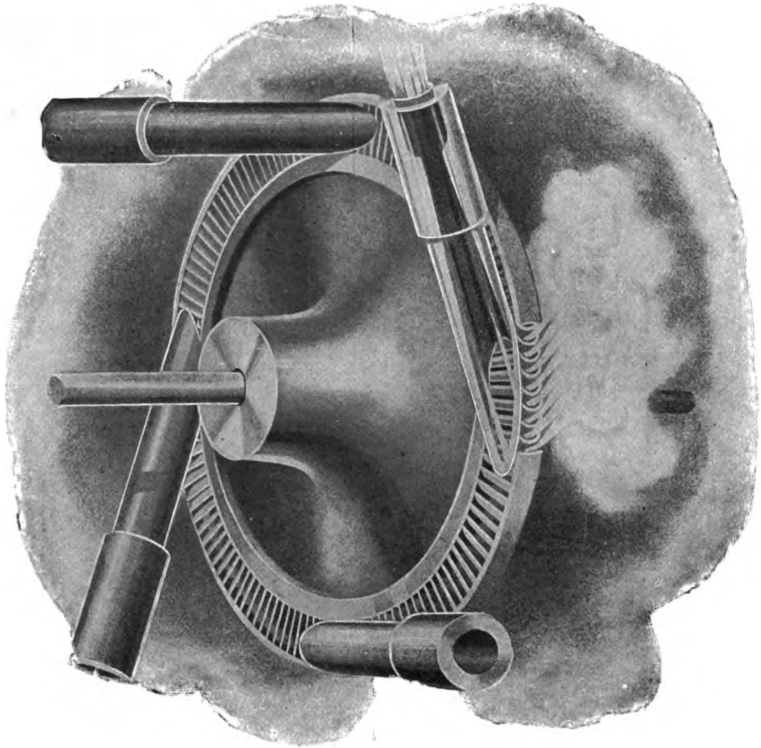

FIG. 1.—Perspective View of De Laval Wheel.

moisture in the steam = O, the specific volume of steam = 2·11 cub. ft. per lb. and the specific quantity of steam = 1.

At line B, the smallest section of the nozzle, the pressure = 110 lbs. per sq. inch above the atmosphere. The percentage of moisture in the steam = 4 per cent. The specific quantity of steam = 0·96. The velocity of steam = 1,500 ft. per sec., and the specific volume of steam = 3·5 cub. ft. per lb.

At line C, the largest section of the nozzle—

Pressure = 28 in. of vacuum (or 2 in. of mercury absolute).
Percentage of moisture in steam = 24 per cent.
Specific quantity of steam = 0·76.
Velocity of steam = 4,127 ft. per sec.
Specific volume of steam = 256·8 cub. ft. per lb.

For this pressure and vacuum the proportion between the areas of the smallest and largest sections of the nozzles should be as 1 to 27·23.

The kinetic energy of 1 lb. of dry saturated steam expanded in conical nozzles is represented by formula $\frac{V^2}{2G}$ which equals the number of B.T.U. given up by the steam during expansion multiplied by Joules equivalent. Therefore—

$$\frac{V^2}{2G} = x \text{ B.T.U.} \times 778 \text{ ft.-lbs., or } V = \sqrt{2G \times x \text{ B.T.U.} \times 778}.$$

From this formula the following examples of the rate of outflow and kinetic energy of dry saturated steam expanded adiabatically in properly constructed conical nozzles are calculated:—With 100 lbs. per sq. inch initial pressure and exhausting to atmosphere, the velocity of outflow is 2,717 ft. per second. The kinetic energy per lb. of steam per hour is 31·86 foot-pounds per second.

Exhausting into 25 in. vacuum—

The velocity = 3,520 ft. per second.
The kinetic energy = 53·47 foot-pounds per second.

Exhausting into a 28 in. vacuum—

The velocity = 3,871 ft. per second.
The kinetic energy = 64·66 foot-pounds per second.

Or again, with 200 lbs. per sq. inch initial pressure, and exhausting to atmosphere—

The velocity = 3,115 ft. per second.
The kinetic energy = 41·87 foot-pounds per second.

Exhausting into 25 in. vacuum—

The velocity = 3,810 ft. per second.
The kinetic energy = 62·64 foot-pounds per second.

Exhausting into 28 in. vacuum—

The velocity = 4,127 ft. per second.
The kinetic energy = 73·50 foot-pounds per second.

Having now arrived at the kinetic energy of the steam, the next point is to arrange that the largest possible amount of this kinetic

energy should be utilised by the vanes of the wheel for the production of mechanical energy. In these turbines the nozzle is placed at an angle of 20° with the plane of rotation. This is shown in Fig. 3, there

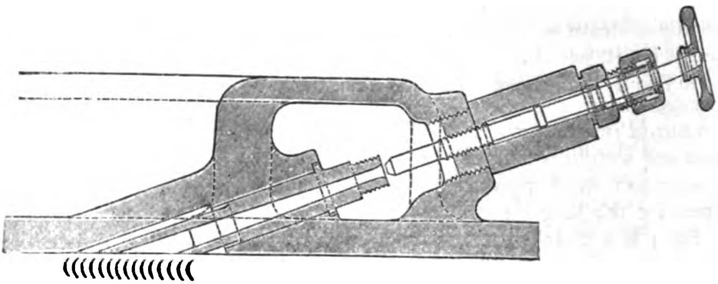

FIG. 3.—Arrangement of Nozzle and Blades.

being only a space of $\frac{1}{16}$th in. between the end of the nozzles and the buckets of the wheel. The most efficient speed for the buckets is clearly that speed at which the steam will leave the buckets at the lowest actual velocity. With the nozzle at an angle of 20° this is obtained when the wheel runs at 47 per cent. of the velocity of the outflowing steam; then the steam leaves the buckets at 34 per cent. of the initial velocity, and as the energy given up by the steam is proportional to the square of the velocities, we have—

$$\frac{Vi^2 - Vf^2}{Vi^2} = \frac{1 - 0{\cdot}34^2}{1} = 88 \text{ per cent.}$$

That means that a wheel running at 47 per cent. of the velocity of the outflowing steam, 88 per cent. of the total energy of the steam would be absorbed by the wheel for the production of mechanical energy.

From this rule the best speed for any De Laval wheel can be easily calculated, and in the nozzle shown on Fig. 2, where the initial pressure was 200 lbs. per sq. inch above atmosphere and the vacuum 28 in., the steam leaves the nozzle at 4,127 ft. per second, therefore the correct speed for the centre line of the buckets would be 47 per cent. of 4,127 or 1,940 ft. per second, or about $22\frac{1}{2}$ miles per minute. This tremendous speed is, however, too high for practical purposes at present, and the highest speed yet used in any of De Laval's wheels is 1,380 ft. per second, this being in the 300-H.P. size turbine.

The speeds of some of the sizes are as follows :—

Size.	Diameter of wheel.	Revolutions per minute.	Peripheral speed per second.
5 H.P.	4 in.	30,000	515 ft.
30 „	8·7/8 in.	20,000	774 „
100 „	$19\frac{3}{4}$ in.	13,000	1,115 „
300 „	30 in.	10,600	1,378 „

The question has often been raised—why not make the wheel of larger diameter and so get a slower speed of rotation? There are, however, two points to be taken into consideration in the question of wheels rotating at a high speed, one of these being the strength of the material of which the wheel is constructed, and the other the surface or skin friction of the wheel in the medium in which it rotates. This resistance is of considerable magnitude, and it was found that it increased more rapidly with the diameter of the wheel than with the number of revolutions; and for this reason, and also on account of the bulk and weight, small wheels running at a high speed were used for machines of small power, and larger wheels running at a modified speed for the larger power.

Fig. 4 is a chart of the stresses in a 50-H.P. wheel, and shows that both the radial stresses P and the tangential stresses S increase with the radius, and also that the tangential stresses increase towards the hole in the centre; therefore in all the larger sizes the wheel is made solid

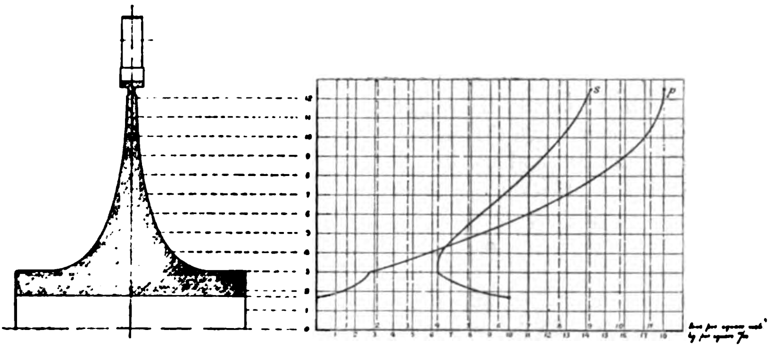

FIG. 4.—Stresses in 50-H.P. Wheel.

without the hole in the centre. To provide against the radial stresses P the wheel is made in the form of a solid disc, round the circumference of which the buckets or vanes are dovetailed in, each bucket being separately made and fitted. These radial stresses are, as shown, largest at the circumference of the wheel, and the wheel is proportioned so that this is the case, and that the weakest place is just where the buckets are dovetailed in. To make sure of this a recess is turned in the outer portion of the wheel, so that if a wheel should burst from excess of speed it would give way at this recess, the vanes would become detached and the wheel would stop rotating. The vanes are so light that no damage would occur. This recess can be seen on the sections shown in Fig. 5, which also shows the method of fixing the shaft and the buckets, and also the shape of the latter. The next serious problem was the balancing of the rotating part, the great difficulty to contend with being that, no matter how carefully the disc was balanced when in a state of rest, its centre of gravity would not exactly coincide with its geometrical centre, and this at a high speed would cause such severe vibration that no bearings could

withstand it. This difficulty was overcome in a very ingenious and simple manner by using a flexible shaft. On account of the very high speed of the wheel a shaft of very small diameter was sufficient, and the bearings supporting this shaft were fixed at a considerable distance on each side from the wheel. The shaft is consequently flexible, and allows the wheel to swing a little in its plane of rotation. With the flexible shaft, however, there are vibrations caused by rotation, which increase with the speed up to a certain point, called "the critical speed of the wheel." At this speed the vibrations suddenly disappear, and the wheel settles down and runs perfectly smoothly in its bearings. This phenomenon is known as "the settling of the wheel," and is caused by the wheel rotating at the slower speeds round its geometrical centre; when it reaches the "critical speed" the shaft is sprung out of

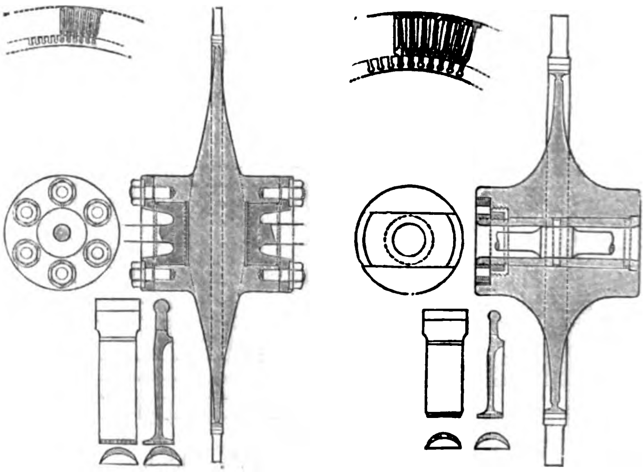

FIG. 5.—Section of Large and Small Wheels.

centre, and the wheel begins to rotate round its centre of gravity. On account of the flexibility of the shaft, and the extreme accuracy of the turning and balancing of the wheel, this settling takes place at from $\frac{1}{6}$th to $\frac{1}{8}$th of the running speed of the wheel; and in fact, in the modern turbines, this effect is hardly noticeable. The speeds of these wheels are far too great for ordinary purposes, therefore it is necessary to reduce them to speeds generally in use. This is done by means of a beautifully-cut double helical gearing, the pinion of which can be seen at "H" in the transverse section on Fig. 6. This pinion is made of very hard steel, while the teeth on the large gear-wheel are made of a softer steel.

In the turbine shown in Fig. 6, which is the 20-H.P. size, there is only one gear-wheel, while in the larger sizes there are two gear-wheels, one on each side of the pinion with, of course, two low-speed shafts; this prevents any great side pressure on the high-speed shaft. The gear is generally arranged for a reduction of speed of ten to one,

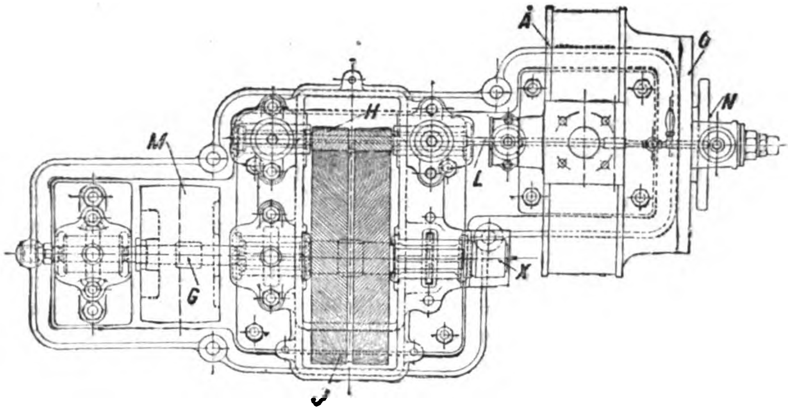

FIG. 6.—Section.

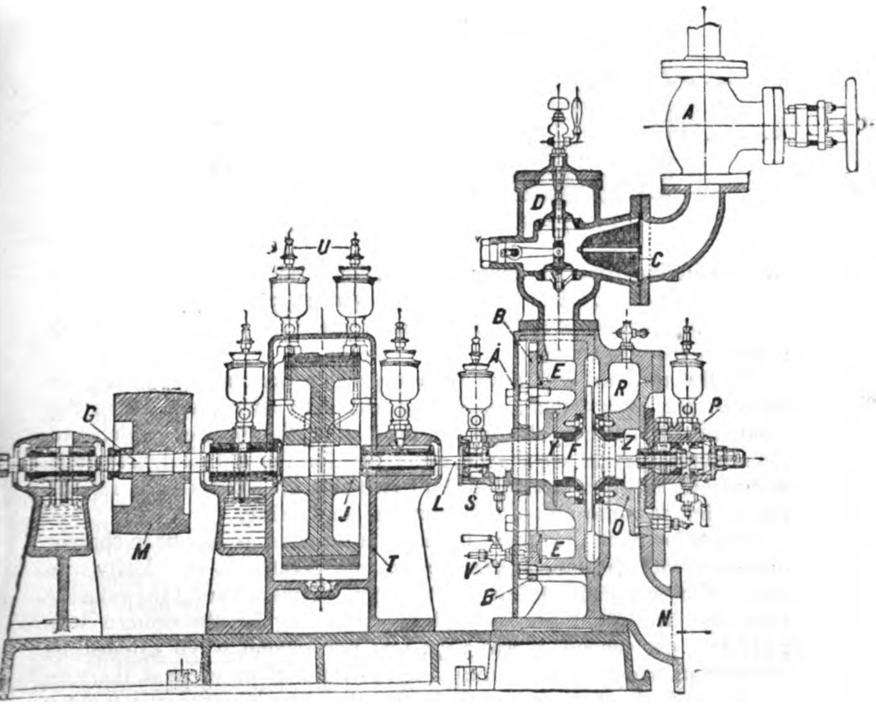

FIG. 6A.—Elevation.

FIGS. 6 and 6A —Section Plan and Elevation of 20-H.P. De Laval Turbine.

and works very well indeed, but in the larger sizes the working is accompanied by a singing or hissing noise, to which there is little objection. What the life of this gear will be is not yet known, but provided it is lubricated with good oil it must be considerable, as, after four or five years' regular working it is impossible to detect any signs of wear. In one or two of these turbines that have come under the writer's supervision the only signs of wear after some months' working were that the driving side of the teeth had a better polish than the other side. The high-speed bearings are all lubricated with sight feed lubricators, while the low-speed shafts are lubricated with the now universal ring system of continuous lubrication.

The very small turbines are only fitted with one steam nozzle, but quite a large number are used with the large sizes. Each nozzle has its own stop valve, as shown on Fig. 3, so that if the turbine is running on partial load, one or more nozzles can be turned off so as to work the remaining nozzles at their best efficiency. The effect of this will be apparent in some tests quoted later on.

The governing of these turbines is effected by means of a very simple and ingenious type of centrifugal governor attached to the end of the low-speed shaft, the construction of which is shown in Fig. 7. The

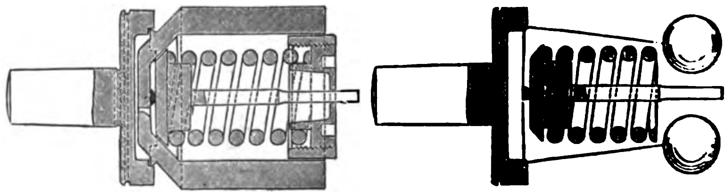

FIG. 7.—Section of Centrifugal Governor.

two expanding parts are supported on knife edges, and so work with very little friction. The action of the governor is to force out the central pin, which presses on a lever, and this in turn actuates a balanced throttle valve.

All the turbines will work with any steam pressure between 50 to 200 lbs. per square inch, exhausting either to atmosphere or to the condenser. The only change required is in the nozzles, which are interchangeable and are shaped differently for the different pressures. Sometimes turbines are fitted with two sets of nozzles—one set for exhausting to atmosphere, and one for condensing.

The velocity of the steam leaving the nozzles, as has been shown, increases with the initial pressure, but the great gain in velocity was obtained by exhausting into a high vacuum. Thus, whereas the velocity with 100 lbs. initial pressure when exhausting to atmosphere was 2,717 feet per second, it was 3,871 feet per second when exhausting into a 28 in. vacuum. This means that, with a 28 in. vacuum, there is a saving of about 50 per cent. in the steam used, since the kinetic energy is proportionate to the square of the velocity. Therefore, if high efficiency is required, it is essential that a reliable form of condenser should be fitted to the turbine.

The following test was made with a 300-H.P. turbine with a stop-valve pressure of 197 lbs. above atmosphere and an average vacuum of 27·4 in. The result with dry saturated steam is first shown, with the turbine at full load—that is, with steam valves full open. The steam consumption is only 15·17 lbs. per B.H.P. hour, and even down to 119 B.H.P., or 36 per cent. of maximum load, the consumption is only 16·4 lbs. per B.H.P. hour, or an increase of 8·1 per cent. This result, as will be noticed, is obtained by closing off some of the nozzles so that the governor does not throttle the steam, and all the expansion takes place on the conical nozzles.

TABLE OF RELATIVE STEAM CONSUMPTIONS FOR DIFFERENT LOADS, PER BRAKE HORSE-POWER HOUR.

SATURATED STEAM.

Nozzle Opens.	Loads B.H.P.	Relative Loads.	Steam per Brake Horse Power.	Increase for Diminishing Loads referred to Maximum Load.
	H.P.	Per cent.	Lbs.	Per cent.
8	333	100	15·17	
7	285	86	15·56	2·6
5	195	59	16·54	9·0
3	119	36	16·40	8·1
SUPERHEATED STEAM.				
			B.H.P. Hour.	
8	352	100	13·94	
7	298	85	14·35	2·9
5	196	56	15·53	11·4

TABLE SHOWING THE SAVING BY USE OF SUPERHEATED STEAM FOR EIGHT AND SEVEN-NOZZLE LOADS.

No. of Nozzles in Use.	Amount of Superheat.	Load with Superheated Steam.	Load with Saturated Steam.	Steam used per Brake H.P. with Superheated Steam.	Dry Steam used per Brake H.P. with Saturated Steam.	Saving by use of Superheated Steam.
8	84° F.	352 H.P.	333 H.P.	13·94 lbs.	15·17 lbs.	8·8 p.c.
7	64° F.	298 ,,	285 ,,	14·35 ,,	15·56 ,,	8·4 ,,

The next set of tests were made with superheated steam, and although the superheat is only a very small amount, still it shows a sensible saving, the full-load test being now 352 B.H.P., the superheat 84° F., and the steam consumption 13·94 lbs. per B.H.P. per hour, or a gain of 8·8 per cent. It is evident from these figures that the superheating is advantageous to the turbine. Further, any reasonable degree of superheat can be used in this turbine because, unlike the ordinary steam engine, you have not to lubricate your steam; and further, the highly heated steam does not reach any moving part of the turbine, as by the time it reaches the wheel chamber it has only the temperature and pressure of the exhaust steam. The effect of superheated steam will be referred to more fully later on.

In concluding with the De Laval turbine, it may be said that it is an ideal form of steam engine for all powers up to 200 or 300 H.P., and it is particularly well suited for driving dynamos. It requires practically no foundations and extremely little attention. It can be started and run up to full speed, even when quite cold, in a moment. No damage can occur from the boiler priming or water collecting in the pipes, as it will only slightly reduce the speed of the wheel for the moment. Considerable advances may be expected in the application of this turbine for small installations.

The Parsons Turbine.

This turbine is the best known, at least by name, to every one in this country. [The author, in his paper as read before the Dublin Section, describes in detail the construction of the first Parsons turbine, and also traces the history of its development up to the present day. But in view of the numerous papers on this subject which have been published in the Journal, much of his detailed description is omitted.] Mr. Parsons has done more for the advancement of steam turbines than any man in the world, and his success was due to his bold departure from the prevailing idea of his time—that the rotary engine should work with a steam-tight joint, and that the power of the steam should be utilised by causing it to flow from one steam-tight chamber to another. He therefore designed his turbine to work on the reaction principle, as distinct from the action or impulse turbine of the De Laval type. Instead of the steam imparting all its energy to one set of vanes, it is made to act on a large number of sets of vanes in succession, these being so arranged that the steam gives up a portion of its energy to each. The steam enters at the upper end [see Figs. 1 and 2 in Messrs. Parsons, Stoney and Martin's paper, published in this number.] It is then deflected, or, rather, directed, by the fixed blades, so that it flows on to the moving blades at the proper angle; after passing through the ring of moving blades, it again passes through a ring of fixed blades, and so on through whatever number of rings is necessary. This type of turbine is generally called a multiple expansion re-action turbine to distinguish it from the single expansion impulse turbine of the De Laval type.

The expansion of steam in this turbine practically follows the

adiabatic curve. The speed of the steam is usually about 600 feet per second, and it is apparent, under these circumstances, that the moving blades, on account of only having to absorb a small portion of the kinetic energy at each ring, can run efficiently at a low speed, and the larger the number of rings or blades the less the drop in pressure in each, and consequently the slower the speed of the turbine. The number is, however, limited for mechanical reasons, as the shaft would get too long between the bearings, and would be inclined to whip or spring.

The first ring of fixed blades generally has only a few guide blades in it, the rest of the rings being solid. The number of blades in the fixed rings will then increase towards the low-pressure end. This, of course, is to allow for the proper expansion of the steam. The moving rings of blades are, however, made with the blades all round the circumference.

It was on this multiple expansion principle that Parsons started to build turbines, the first of which he brought out in the year 1884. It gave 10 B.H.P. and ran at a speed of 18,000 revolutions per minute. It was coupled to a special design of dynamo, and after working successfully for some time was presented to South Kensington Museum, where it can still be seen.

A 1,500-kilowatt turbo-alternator in use at the Neptune Bank Power Station in Newcastle-on-Tyne is specially interesting, as both reciprocating engines and turbines are used side by side, which renders possible a good comparison of the space required and the relative size of the two kinds of plant. The steam engines can each indicate up to 1,400 H.P., while the turbine is equivalent to an engine which would indicate 2,500 H.P. The relative floor areas occupied by a vertical plant and by the turbine is about 2½ to 1·0, the vertical set taking about 0·5 of a square foot per kilowatt, while the turbine only occupies about 0·2 of a square foot. In the very large sizes these figures are reduced, but the proportions remain the same, while as regards the height, for 3,000 H.P. sets a modern vertical steam engine would be about 36 feet high, while the turbine would only be 9 feet.

With reference to the reliability of these turbines for driving dynamos, there is a case lately quoted which is interesting in showing how reliable a turbine is, and the small amount of repairs it requires. This referred to a 600-H.P. Parsons turbine driving a dynamo, supplied by Brown Boveri, of Baden. The turbine ran continuously under load for a period of 7,000 hours, which would equal about two years' average work at 10 hours per day, including Sundays and holidays. At the end of this time it was shut down, and the only repairs found necessary were the reseating of the double beat valve, which only took five hours altogether.

Further, with regard to the oil used for lubrication, it was stated that the oil was only changed once in two years, the consumption being 360 litres, or 95 gallons, per annum.

There was also reference made to a 5,000-H.P. set at Frankfort-on-Maine, which, after a year's service in the Electric Station at 2,800 to 3,200 kilowatts, required absolutely no repairs.

Marine Turbines.—In the year 1894 Parsons formed a separate company for the purpose of developing the turbine for marine propulsion. The company set about building a boat of practical size, and the first practical result was the celebrated "Turbinia." This vessel had a length of 100 feet, beam 9 feet, draught of hull 3 feet, and displacement 44 tons. The total weight of the machinery was 22 tons, the main engines themselves only weighing 3 tons 15 cwt., and these developed a maximum of 2,000 B.H.P., and gave a speed of 34¼ knots. Since that date further experiments were made with a new form of single propeller on each shaft, with improved results. The steam consumption in this vessel was 14·5 lbs. of steam per I.H.P.

Owing to the success of the "Turbinia" other developments followed rapidly, until recently the Cunard Company, acting on the advice of a body of engineering experts specially employed to report on the matter, have decided to adopt turbines for the propulsion of their two new liners, which will be about 760 feet long, with a speed of 25 knots. This will require over 70,000 H.P., which will be divided between four turbines, each driving a separate shaft.

Parsons' Turbine Tests.—We will now briefly look at some actual tests of the steam consumption of Parsons' turbines made under working conditions. The following table shows the consumption of steam for a 200-kilowatt set. It also shows the saving in consumption from using superheated steam.

TABLE I.

Two 200-K.W. Continuous-Current Traction Turbo-Dynamos, for the Corporation of Blackpool.

Pressure of Steam above Atmosphere at Stop Valve.	Superheat at Stop Valve.	Vacuum in the Turbine Cylinder Bar = 39″	Revolutions per minute.	Load.	Steam used.	
Lbs. per sq. inch.	F.°	Inches of Mercury.		K.W.	Lbs. per hour.	Lbs. per k.w. hour.
129	58	27·6	3,045	226	4,975	22·0
122	60	28·4	3,010	232	5,079	21·9
119	0	26·9	3,000	204	4,943	24·2
130	0	28·0	3,010	0	950	—

Another test of a still larger set, having an output of 500 kilowatts with 140 lbs. boiler pressure and no superheat, was specially made to show the effects of the vacuum on the consumption of steam. We have full-load, half-load, quarter-load, and no-load consumption for every inch of vacuum from 28 to 22. At 28-in. vacuum the full-load

consumption is only 22·2 lbs. per kilowatt-hour, and with same load and 22-in. vacuum the consumption is 28·9 lbs., or an increase of 31 per cent. At quarter-load, with 28-in. vacuum, the consumption is 32·4 lbs., and with 22-in. vacuum 46·3 lbs., or an increase of 43 per cent. These figures proved conclusively the enormous gain there is in having a good vacuum. It is calculated that on full-load there is a gain of at least 4 per cent. in steam consumption for every extra inch of vacuum above 25 inches, and on lighter loads the gain is greater.

TABLE II.

Test of 500-k.w. Turbo-Dynamo.

Vacuum constant from Full-load to No-load.	Consumption per Kilowatt-hour.			
Inches of Mercury.	Full-load.	½	¼	No-load.
29	—	—	—	1,500
28	22·2	25·6	32·4	1,700
27	23·1	26·9	34·5	1,900
26	24·0	28·2	36·6	2,100
25	25·1	29·7	39·0	2,300
24	26·2	31·2	41·2	2,500
23	27·5	32·9	44·8	2,700
22	28·9	34·7	46·3	2,900

Table III. gives results of a test of a 4,000-H.P. Parsons turbo-dynamo made by Brown Boveri, which is at the Frankfort-on-Maine Power Station. This turbine is built for 186 lbs. pressure per sq. inch; 200° F. superheat equivalent to a total temperature of 300° C.; speed, 1,360 revolutions. The particulars of this test were published in the *Tramway and Railway World*, January 14, 1904, and it is therefore one of the most recent tests for a large-size turbine. The superheat on the full-load test works out at 227° F., but shows only 152 lbs. steam pressure, and a vacuum equivalent to 27 in. of mercury. On this load the consumption of steam reaches the remarkably low figure of 15·1 lbs. per kilowatt-hour. This test, which was obtained in actual station service, has never been sensibly beaten. In fact it must be very near the record, and therefore it is not too much to claim that steam turbines take no more steam than reciprocating engines of equal size.

TABLE III.

TEST OF A 2,600 K.W. TURBO-DYNAMO.

Steam Pressure at Stop Valve in lbs. per sq. inch.	Temperature of Superheated Steam. Deg. C.	Output Kilowatts.	Vacuum per cent.	Steam Consumption in lbs. per k.w.
181·0	298	1,945	93·2	16·0
183·5	295	2,518	91·8	15·75
152·0	312	2,995	90·0	15·1

THE CURTIS TURBINE.

We now briefly describe a turbine of American origin, which was developed by Mr. C. G. Curtis in the year 1895. This turbine

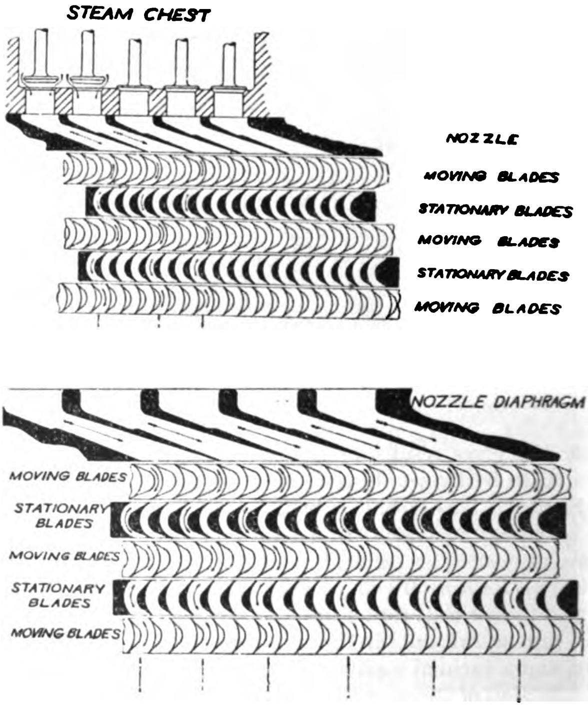

FIG. 8.—Diagrammatic Section of Nozzle and Wheel, Curtis Turbine.

is different from either of those we have considered already, in that it is now generally arranged with a vertical shaft and has, so far, only been used for driving dynamos which are placed over

the turbine and really make a very compact plant, occupying a very small amount of floor space. It avoids the very high speeds of the De Laval wheels, and has not the great number of vanes of the

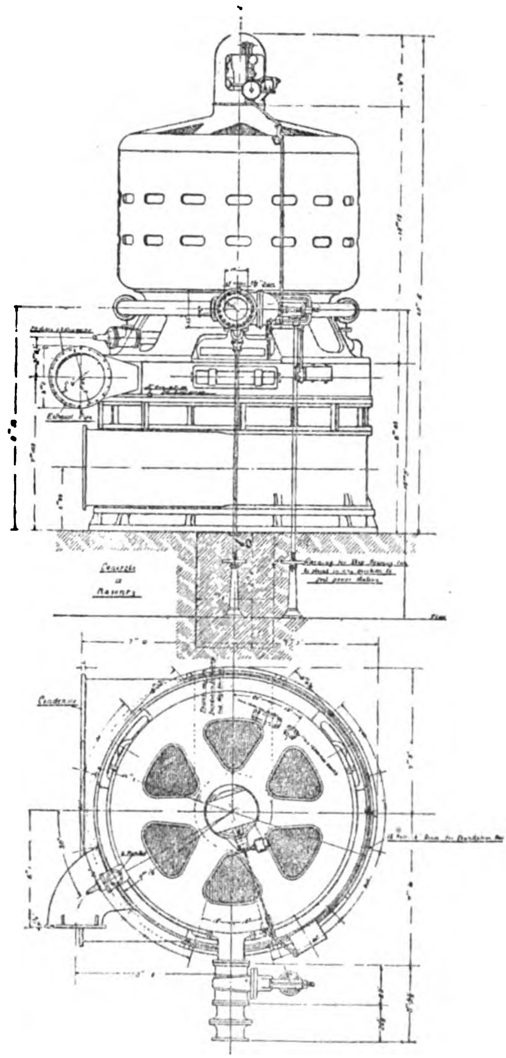

FIG. 9.—Plan.

Parsons, and it is claimed that it is cheaper to build. Mr. Curtis makes use of the steam partly on the action principle, and partly on the re-action principle like Parsons. Fig. No. 8 shows the principle of the turbine. The steam is admitted through a number of nozzles which

are slightly conical. In these the steam partially expands and acquires a velocity of about 2,000 feet per second, thus converting that portion of its potential energy into kinetic energy, which is due to the expansion between the limits of pressure used in the first part of the turbine. It then expands again through another set of nozzles, and through more moving and fixed rings of blades. This process may be repeated two, three, or four times, each time being called a stage, the number of stages depending on the steam pressure and whether exhausting to atmosphere or condenser, and also on the required speed ; generally speaking, the slower the speed the more stages there must be.

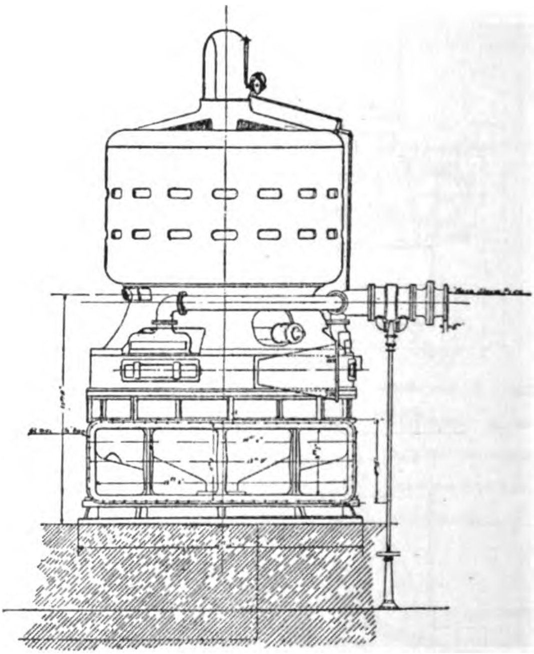

FIG. 9A.—Elevation.

FIGS. 9 and 9A.—Plan and Elevation of 5,000 k.w. Curtis Turbo-dynamo.

The steam enters the turbine when all the nozzles are open, in a broad belt, and the governing is effected by the successive closing of the nozzles, thus narrowing the steam belt at the admission. In the original form of this turbine all the nozzles, except the first, were arranged so that each one would be either full open or shut, and in the first nozzle there was a centrifugal governor which throttled the steam. This was arranged so that the first nozzle was full open before the second opened. The second would then open full bore, and the steam would be throttled in the first nozzle to the required amount. As soon as the first and second were full open, the third nozzle would open full, and the first would be again throttled, this process being repeated till all the nozzles were full open. From this it is seen that only a portion

of the steam was throttled by the governor. However, in some of the more recent types, the governing is effected solely by the opening and closing of the nozzles, and therefore on certain loads one of the nozzles may be opening and closing very rapidly, so as to maintain the proper speed. The means of operating these nozzles is very ingenious. The governor, which is of a powerful and very sensitive centrifugal type (and mounted at the top of the turbine on the end of the shaft), actuates a small controller on the side of the turbine case. This controller has a contact for every nozzle. The nozzles are worked by steam relays, the valves for these relays being actuated by electro-magnets which are operated by the controller, the current for which can either be taken from the generator itself, but better still, from the station 'bus-bars or a storage battery.

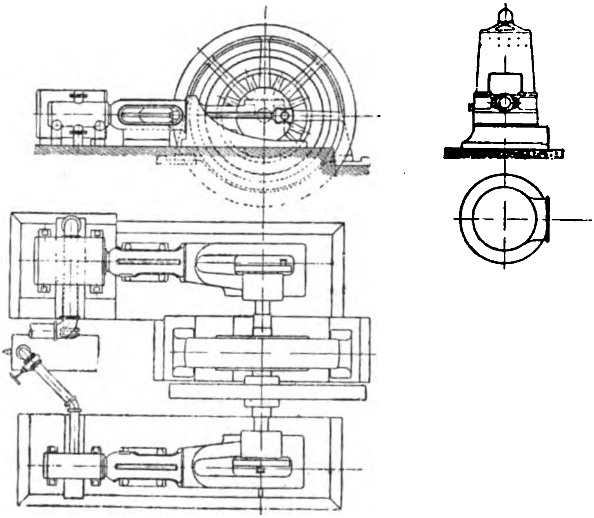

FIG. 10.—Comparative Sizes of 500 k.w. Cross-compound Engine and Dynamo and 500 k.w. Vertical Curtis Turbo-dynamo.

It will be noticed that only two nozzles on Fig. 9 are shown open, but, by the time the steam has got to the end of the second stage, it is passing through all the blades. In some cases some of the nozzles in the second and third stages can be shut off for very light loads, but the practical economy is very little.

Fig. 9 shows a drawing of a 5,000-kilowatt Curtis Turbo-dynamo, which gives an idea of the general appearance of dynamo and turbine. This set occupies a height of 25 ft. 6 in., and a floor of 14 ft. 10 in. square. There are two exhausts to this turbine, the upper one for exhausting to atmosphere and the lower one for exhausting to condenser. This is the usual practice with this turbine, and allows for exhausting the steam through an extra stage when condensing. In some forms of the turbine the base actually contains the surface con-

denser; in the drawing, however, only the flange for bolting on the condenser is shown.

The bottom bearing which supports the whole weight of the turbine-wheel and armature, consists of circular cast-iron plates, one on the shaft, the other on the base. Through a hole in the centre of the lower plate oil is pumped in under a pressure of 200 to 400 lbs. per sq. inch; this oil flows out all round the plates and then passes up to oil the guide blocks. The amount of oil for a 2,500-H.P. turbine is said to be two gallons per minute. After being used, it is filtered and cooled and used over again.

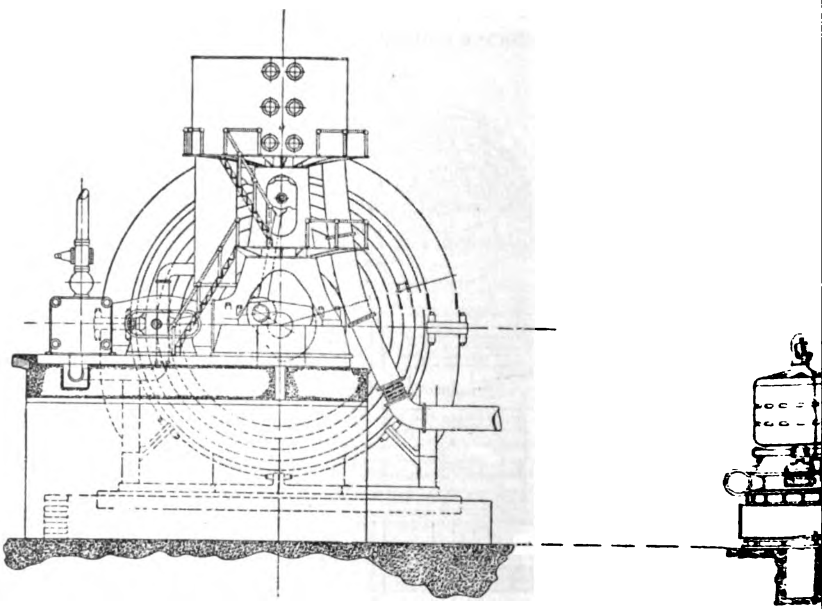

FIG. 11.—Comparative Sizes of 5,000 k.w. 75 r.p.m. Engine and 5,000 k.w. 500 r.p.m. Curtis Turbine.

Fig. 10 shows the relative amount of floor space and height taken up by a 500-kilowatt 100 r.p.m. cross-compound engine with dynamo, and a Curtis turbine of same output at 1,800 r.p.m. The comparison is very striking, but in this case it might be said that it is not a fair comparison to make between a vertical turbine and a horizontal engine.

Fig. 11 shows a comparison between a 5,000 H.P. vertical compound engine of the Manhattan type and a vertical turbo-dynamo of same power. To give some actual figures, we may take the 2,500-kilowatt Musgrave engines in Glasgow Tramway Station, each of which with dynamo occupies 1,392 sq. ft., or 56 sq. ft. per kilowatt, and the extreme height 34 ft.; while the 5,000-kilowatt Curtis turbine with dynamo, at Chicago, occupies 175 sq. ft., or 0·035 sq. foot per kilowatt, with a total height of 25·6 ft.

The steam consumption in these turbines is very favourable, but as yet there are very few published results. The best published result is a steam consumption of 16 lbs. per kilowatt turbine at full load, with 200 lbs. pressure, 150 degs. F. superheat, and 28·5-in. vacuum. Also a similar turbine with 140 lbs. pressure and 150 degs. F. superheat, and 28·5-in. vacuum, 16·75 lbs. per kilowatt, and without the superheat 19·2 lbs. This is, however, a very high vacuum, but reducing the vacuum 0·5 of an inch to 28-in. the consumption would only increase to 17·25 lbs. in one case and 19·7 in the second. From this you will see that these turbines are affected about the same as Laval or Parsons, both by increase of vacuum and superheat.

RATEAU'S TURBINE.

The Rateau turbine, the last it is proposed to consider here, was designed to get rid of the objectionable features of the De Laval and Parsons turbines, and yet embody the good points of both. The disadvantage of the De Laval turbine is its high speed, and of the Parsons the extremely small clearances beyond the end of the fixed and moving blades to avoid a too great leakage of steam past these. The good feature of the De Laval was the large clearance that could be allowed between the wheel and the casing, and the good feature of the Parsons the comparatively much slower speed of rotation. Rateau then designed his turbine like Parsons in that the steam was expanded through a large number of stages, and each turbine was therefore made to consist of a large number of rings of blades; but he made it like De Laval's in that the steam acted on the impulse principle. Each wheel is enclosed in a separate chamber, the nozzles or guide passages being in the diaphragms between the wheels, so that the steam, after passing through the first set of nozzles on to the first wheel, exhausts out of that wheel chamber through a set of nozzles in the diaphragm on the next wheel.

Fig. 12 shows the outer appearance of a turbine of 500 H.P. Looking towards the exhaust or low pressure end it will be seen that it resembles the Parsons, being divided along the axial line, so that the top half can be lifted off. It is also compounded like the Parsons, in that the low-pressure end is enlarged in diameter.

Fig. 13 shows the inside, one-half of the outer case and half of each diaphragm being lifted off, exposing to view the large number of wheels which are formed of discs of thin sheet steel carrying cylindrical-shaped buckets on the periphery which, are riveted to a band of steel welded to the disc. This gives a very light and strong construction, maintaining its balance at all speeds. Each of these wheels is separately keyed on to the shaft. The upper half of the diaphragms are not shown here, but they are fitted into the cylindrical casing and reach to the shaft, but are not tight enough to form a bearing. In fact they are generally left very free round the shaft, and a clearance of 3 or 4 mms. does not appear to affect the efficiency at all. The nozzles or steam passages are in these diaphragms, and are arranged so that the steam impinges on the buckets in much the same way as in the De

Laval, but on account of the large number of stages of expansion, the velocity of rotation of the wheel is low.

These nozzles or guides are fewer in number in the diaphragms at the high-pressure end of the turbine, gradually increasing in number towards the low-pressure end.

It will also be easily understood that the axial or end thrust of the Parsons turbine is not felt in this turbine, as each wheel rotates in a closed chamber—the steam exerts a practically even pressure on both sides of the wheel, so that no compensating pistons or thrust blocks are required when driving dynamo or other fixed machinery. But when used for marine propulsion, where there is an end thrust caused by the propeller, the last few diaphragms are dispensed with, and the rotating blades mounted on a drum on the shaft, this portion being then very like the Parsons turbine. In this case, then, there is an axial thrust caused by the steam which is arranged to balance the thrust of the propeller. Further, when required for marine work, a number of vanes are provided on the low-pressure end—the curvature of these is in the opposite direction to the other moving vanes. Steam is then admitted through special nozzles on the low-pressure end, and the turbine rotates in the opposite direction.

These turbines uphold the great economy of all modern turbines, and, for the purpose of quoting one test on a 500 E.H.P. turbo-dynamo, running at a speed of 2,400 revolutions, the published results are converted into English standards, which are, that with 133 lbs. absolute initial pressure and a vacuum of 1·5 lbs. per sq. inch, the steam consumption was 21 lbs. per kilowatt per hour. This is a very fair result, as the initial pressure was not high, the vacuum was nothing like as good as those with which the other turbines were tested, and there was no superheat.

There is one very interesting peculiarity in the steam turbine, and, as Rateau first pointed it out, it may be quoted here, and that is its remarkable efficiency with very low-pressure steam. Rateau designed a turbine for the Bruay mines in France; this was coupled to a dynamo and gave an output of 247 kilowatts, the initial steam pressure was 1·01 kgs. per cm.^{2} absolute, or about 14·14 lbs. per sq. inch absolute. The exhaust pressure was 0·184 kgs. per c.m.^{2}, or, say, 2·6 lbs. per sq. inch absolute (not a very good vacuum), and the steam consumption was 16·95 kgs. per E.H.P. per hour, or 44 lbs. per kilowatt per hour, and this with steam that was actually under atmosphere pressure.

This has, of course, suggested using the exhaust steam from large reciprocating engines to drive turbines, and Rateau is now experimenting on the subject, as it shows that a greatly increased power can be got out of the exhaust steam by passing it through a turbine to the condenser, than by joining up the exhaust of the engine direct to the condenser.

Having now considered the four turbines which are of most practical importance at present, it is only right to say that they by no means exhaust the turbines, as Germany is now coming to the front with a large single wheel impulse turbine, which has some very novel features, and will, no doubt, prove itself to be highly efficient; but, as it is

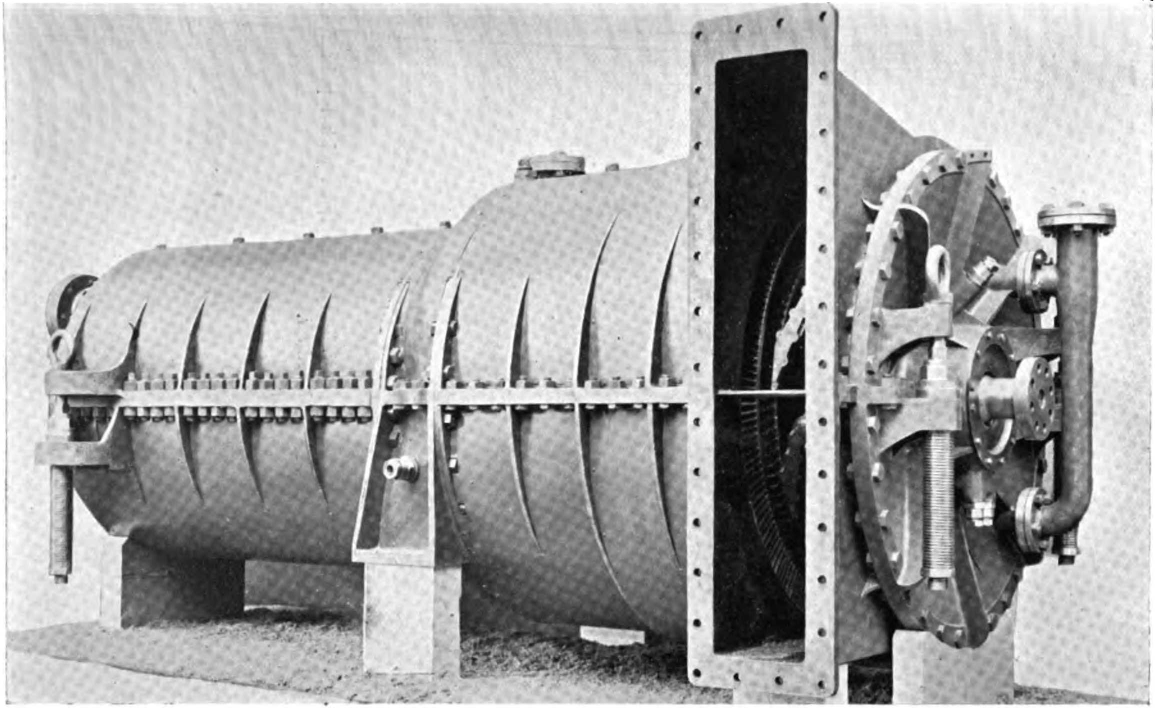

FIG. 12.—External Appearance 500 H.P. Rateau Turbine.

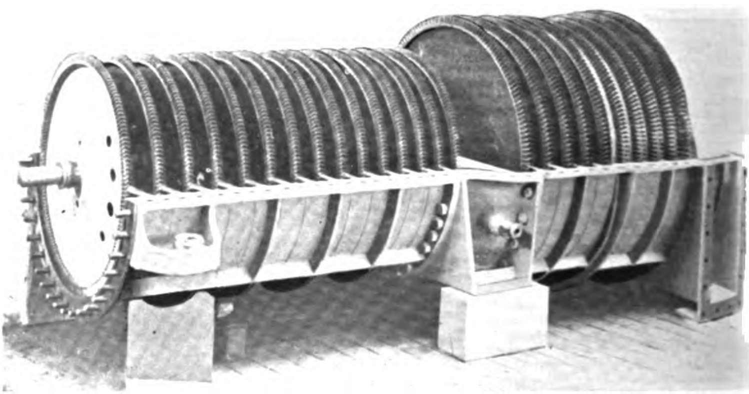

FIG. 13.--Internal Appearance 500 H.P. Rateau Turbine, with top half of case lifted off.

not yet regularly on the market, will not be considered in this paper.

The author desires, however, to make a few remarks on the effect of vacuum and superheat. The benefits from a good vacuum are greater in practice in a steam turbine than in the reciprocating engine. In the reciprocating engine the value of a very high vacuum is partly neutralised by the increased condensation in the cylinder, due to the lower temperature of the walls of same; and again, it is practically impossible in the reciprocating engine to expand the steam down to the pressure of the condenser without increasing the size of the low-pressure cylinder to such an amount that more is lost by the extra mechanical friction than gained by the better vacuum.

In all the turbines, a large part of the gain from the vacuum is caused by the immensely increased expansion of the steam, and the steam being confined to a fixed space, it means a much greater rate of flow, or outflow (according to the type of turbine), and consequently increased kinetic energy. A high vacuum also acts in another way—namely, in reducing the surface or skin friction. The surface friction in a wheel rotating at a high velocity is a very serious factor in the power of a wheel, and is directly proportional to the density of the medium in which it revolves. Consequently it is theoretically fifteen times as much at atmospheric pressure as at 1 lb. absolute. To quote a specific case—to rotate a 150 H.P. De Laval wheel at normal speed in steam at atmospheric pressure took 35 H.P., but to run the same wheel in a 28 in. vacuum only took 2·½ H.P. Consequently it is essential for good results with steam turbines to have as perfect a vacuum as possible, both on account of the extra energy of the steam, and also to reduce the surface friction of the wheel, the saving amounting to 4 or 5 per cent. for each extra inch above 24 to 25 inches vacuum.

Engineers should, therefore, when laying out turbine plants, try and arrange to have the exhaust pipe between the turbine and condenser as short as possible, and of such an area that there will be little or no loss of pressure.

It is not quite so easy to see why superheating effects such a marked increase in the efficiency of the steam turbines, which is greater than can be accounted for by thermo-dynamic reasons. In the tests of both De Laval and Parsons turbines a gain is noticeable. One case showed a gain of 8 per cent. in a 300 H.P. Laval turbine, with 84 degs. F. superheat, and the average gain in the Parsons for moderate superheat works out about 1 per cent. every 8 degs. F. of superheat. Part of this gain is, of course, due to the reduction in the amount of initial condensation in the steam, thus leaving a larger amount of the steam to expand doing work. But a considerable portion of the gain must be due to reduction in the friction. In the reciprocating engine the mechanical friction is a large item, sometimes amounting to nearly 25 per cent. of the total power of the engine. In the turbine, on the other hand, the mechanical friction is a small amount, being confined to two bearings—but the friction of the wheel against the steam is a serious amount, and the wetter the steam the greater this friction. Also in some forms of turbines a large amount of condensed steam adheres to

the guide blades and comes in contact with the revolving blades, thus causing considerable loss of power. Also the condensed steam adhering to the walls of the steam passages must retard to some small extent the free passage of the steam, and although all the friction is not lost power, as some of it may be returned to the steam in the shape of heat, still the wetness of the steam seriously impares the efficiency. This can be obviated by the superheating of the steam, and the greater the superheat the greater the gain. Further, there is no necessity to lubricate the steam in turbines, and there are no rod packings to maintain, consequently any reasonable superheat can be employed provided the revolving blades are made of a suitable metal that will not weaken under the combined effects of the high temperature and the centrifugal force.

Summing up, the author gives under a few headings, the different reasons for his strong belief in the steam turbine :—

(1) The reciprocating engine is now very nearly as perfect as it is likely to be, both from a mechanical and thermal point of view, while the turbine is still only being developed.

(2) Steam turbines are cheaper to build than reciprocating engines of equal power.

(3) They occupy only one-fifth to one-tenth the cubic space, and require considerably less attendance, being the simplest form of engine.

(4) They use no more steam than the highest grade reciprocating engine.

(5) On account of the practical absence of vibration, they require little or no foundation.

(6) They have a perfectly even turning movement, consequently have no dead points, and require no flywheel; there are no heavy masses of metal to reciprocate, causing great waste of power.

(7) They require no internal lubrication, consequently, as the condensed steam is perfectly clean and free from oil it can be pumped back into the boiler without any purification, thus saving the costly and troublesome oil separating plant which is usually fitted to large installations.

And, lastly, the life of a steam turbine, that is the period through which it will maintain its initial efficiency without serious repairs, is very much greater than that of the reciprocating engine, as the wear on the bearings is only that due to the steady weight of the wheel and not to any working forces. There is also the absence of cross-heads, slides, eccentrics, cylinder linings, piston rings, packings, etc., all of which require regular attention, and which have no counterpart in the steam turbine.

These principal features are evident to any one who gives an impartial consideration to this subject, especially when it is remembered that only 20 years have elapsed since the first practical steam turbine was made, and that already the largest steam plants under construction in this country and the largest vessels that are being built are being equipped with turbine engines.

In conclusion, the author desires to thank Messrs. Greenwood & Batley, of Leeds; the British Thomson-Houston Co., Messrs. C. A.

Parsons & Co. of Newcastle-on-Tyne, and the Editor of *The Engineering Magazine* for very kindly lending him a number of the illustrations and blocks which have been used for illustrating this article, and also for the large amount of trouble they went to in supplying him with information on their respective types of turbines.

Mr. M. RUDDLE said he had formed no opinion as to the relative advantages of turbines and reciprocating engines, but he was not at all satisfied that the turbine was yet reliable. Much was made of the installation of turbines by the Metropolitan Company, but this had been a matter of compulsion on account of vibration troubles with reciprocating plant. He had visited the station twice in one week, and had found the turbines open for repairs. Mr. Ruddle.

Mr. W. TATLOW suggested that turbines might be usefully employed to obtain additional power by utilising the exhaust steam of existing non-condensing engines. He thought that there was a theoretical advantage in superheating the steam for turbines apart from the reduction of frictional loses due to condensed water, as the reduction of density of the steam would give a higher velocity and therefore more energy per pound. Mr. Tatlow.

Mr. M. C. OLSSON said he was rather surprised at the claims for economy through superheat in turbines, as he thought it had been the general opinion that superheat did turbines less good than reciprocating engines. He drew attention to performances of reciprocating engines worked with the Schmit system of superheat, and mentioned the case of a 300 I.H.P. engine built by Messrs. Easton of Manningtree, and tested by Professor Ewing. A consumption of 9 lbs. of steam per indicated horse-power hour was attained, and this compared very favourably with the figures for the 5,000 k.w. Curtis turbine with 15·4 lb. of steam per kilowatt-hour. He could not agree with Mr. Porte's statement that a great deal of power was wasted in moving reciprocating parts, for it was well known that a well-constructed steam engine of modern design was a very efficient machine, and a mechanical efficiency of 95 per cent. was said, on very good authority, to be attainable. Mr. Olsson.

Mr. H. G. WHITING (*communicated*): Before venturing on any remarks on Mr. Porte's paper, I wish to congratulate him for bringing such an interesting subject before the members of this Institution. Mr. Whiting.

In considering the paper there is one thing which I think would have greatly interested the members and which I wish he had given us more information about; that is, the comparative results of steam consumption, repair costs, oil costs, and other particulars of reciprocating engines of similar size to the turbines of which he has given us data. This would enable one to gauge the advantages and disadvantages much better than otherwise.

Taking a few points mentioned in the paper, Mr. Porte states that turbines are cheaper to build than reciprocating engines of equal power. This may be so, but unless the cost of running them is less expensive this advantage would not carry so much weight; for if the running expenses prove to be more than those of the reciprocating

Mr. Whiting.

engine, the extra cost of the latter might be wiped out after using for a year or two.

The small space occupied by turbines would be an important factor in the advantages over reciprocating engines in most cases; but where power-houses are being built on the outskirts of towns for supplying power in bulk, as is done now in a number of cases, land is not so expensive and the amount of space occupied by engines would not be such a matter of importance.

Regarding attendance, I fail to see that any saving would be effected, except possibly in comparing with some marine type or cross-compound engines, for one man can well look after a fair number of engines quite well. In cases I know of, a driver will look after as many as six or more high-speed reciprocating engines, and I should say quite as many of this type could be efficiently attended to as turbines.

Steam consumption is a matter of very great importance, and I much wish Mr. Porte had given us more figures for comparison. Although he does not state that turbines take less than reciprocating engines of same horse-power, until it is proved that they are better in this respect there is no advantage on this score; indeed, it may be that reciprocating engines can be made to give better results than turbines. For engines of anything up to about 250 H.P. I believe the advantage lies with the reciprocating engine.

A good vacuum, as 28 inches, on which the high efficiency of turbines so much depends, may be very expensive to maintain. It involves increased capital expenditure in condensers and pumps, and requires a good deal of care and attention to maintain. Again, bringing steam down to the temperature necessary for this vacuum means using a large quantity of water which is not always easily obtained at a low temperature.

If the condensed discharge is required again for feeding boilers, the temperature of same is necessarily very low as compared with the temperature of water from a vacuum of, say, 23° to 25°; and consequently the loss involved in heating up the same for boilers again is of some importance, and counts against the extra advantage of 2 or 3 inches of vacuum.

In central stations, also, it is not always possible to run a turbine at its maximum load, and from what I recollect of Mr. Porte's figures, as compared with a reciprocating engine, the steam consumption goes up much more rapidly as load is reduced on a turbine than is the case with the former.

With the exception of the Parsons and De Laval turbines, I suppose experience has not yet been obtained of costs of repairs with turbines in practical use. I have heard that the blades are all stripped off occasionally, which means not only an expensive job, but the time taken for repair would be considerable. This alone might be of great consequence in a generating station which was running to the full capacity of its plant, and delay of a few days would mean running at great risk with overload or other plant; whereas with engines any ordinary repairs can usually be accomplished in a few hours.

It appears to me that until the advantages of turbines over recipro-

cating engines have been more thoroughly proved by actual practice, the present rush for the turbine is hardly warranted. Mr. Whiting.

Before leaving the matter I would like to ask Mr. Porte if he can tell us why the Blackpool Corporation are having reciprocating engines put in after they have been using turbines, as I understand is the case.

Mr. F. C. PORTE, in reply to the Chairman's remarks, said "that as the casing and blades both expanded and contracted almost to the same amount owing to change of temperature caused by superheating, the loss of efficiency, owing to a different amount of clearance, was not very serious." Mr. Porte.

In reply to both the Chairman's and Mr. Whiting's remarks *re* stripping of blades, he said "he could find no authenticated case of this occurring, except where superheated steam was used on turbines not built for superheated steam; or else, from some cause or other, an extreme amount of superheat was used, which probably affected the strength of the blades and caused some of those at the inlet end to become detached, and these being carried along by the steam would soon strip a large number more."

In reply to a wish expressed that some comparative figures were given, Mr. Porte said "that he stated, when beginning to read his paper, that he only wrote it to describe some of the turbines on the market, and it was impossible to take up the number of questions that could arise that night; so he confined all his comparisons to the statement that the turbine took no more steam than the reciprocating engine." He then again referred to the economy of using high vacua, and, in an example quoted, pointed out that the power required to pump the extra condensing water necessary for an increase from 25 in. to 28 in. vacuum, only amounted under ordinary circumstances to from 1 to 1·5 per cent. of the total power of the turbine; and as this extra vacuum would give 12 per cent. better efficiency, it meant a nett gain of at least 10 per cent., which would in a short time pay for the extra capital cost of the larger condensor, pumps, etc. He also stated that he believed the reason why the turbines were being superseded at Blackpool, was that condensing water was not available in sufficient quantities, and he had not claimed a very high efficiency for turbines except when condensing. He, however, had not exact information on the subject at the time.

He concluded by saying that he thought one of the best arguments that could be used to show there was a great future before the steam turbine, was that so many of our celebrated high-speed engine builders had taken out licenses and were actually manufacturing steam turbines, and were now supplying them in many cases in preference to the steam engine that had made for them their name. This showed that these engine builders knew there was a likelihood of their engines being superseded in certain cases by the steam turbine, and thought it well to be prepared for the change that was taking place.

NOTICE.

1. The Institution's Library is open to members of all Scientific Bodies, and (on application to the Secretary) to the Public generally.

2. The Library is open (except from the 14th August to the 16th September) daily between the hours of 10.0 a.m. and 6.30 p.m., except on Saturdays, when it closes at 2.0 p.m.

An Index, compiled by the late Librarian, to the first ten volumes of the Journal (years 1872-81), and an Index, compiled under the direction of the late Secretary, to the second ten volumes (years 1882-91), can be had on application to the Secretary, or to Messrs. E. and F. N. Spon, Ltd., 125, Strand, W.C. Price Two Shillings and Sixpence each.

A further Index, compiled by the Secretary, for the third ten volumes (years 1892–1901) is now ready, price Two Shillings and Sixpence, and may be had either from the Secretary or from Messrs. Spon.

Publishers' Cases for binding Vol. 32 of the Journal can now be had from the Secretary or from Messrs. Spon, price 1s. 6d. each.

JOURNAL

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Institution of Electrical Engineers.

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The Four Hundred and Eleventh Ordinary General Meeting of the Institution was held at the Society of Arts, John Street, Adelphi, on Thursday evening, May 26, 1904—Mr. J. GAVEY, C.B., Vice-President, in the chair.

The minutes of the Ordinary General Meeting held on May 19, 1904, were by permission of the meeting taken as read, and signed by the Chairman.

The names of new candidates for election into the Institution were taken as read, and it was ordered that they should be suspended in the Library.

The following transfer was published as having been approved by the Council :—

From the class of Associates to that of Associate Members—

Frederick William Herbert Wheadon.

Messrs. R. C. Dieppe and H. G. Wood were appointed scrutineers of the ballot for the election of new members.

The following paper was then read :—

HIGH-SPEED ELECTRIC RAILWAY EXPERIMENTS ON THE MARIENFELDE-ZOSSEN LINE.

By ALEXANDER SIEMENS, Past-President.

On September 4, 1901, Mr. O. Lasche, of Berlin, read a paper on a High-speed Railway Car before the Engineering Conference in Glasgow, which has been published in Vol. 31 of the Journal of this Institution. Since that time three sets of experimental runs have been made with high-speed cars on the military railway between Marienfelde and Zossen, near Berlin, which had been equipped electrically for the purpose, and last autumn speeds of over 200 km. per hour were attained. Although further experiments are in contemplation, it may not be out of place to give a short history of the trials and of the preparation for them, as the main objects of the investigation have been accomplished.

The English Patent 10926/86, "Improvements in the application of Volta Inductors or Secondary Generators for distributing electrical energy and for regulating alternate-current motors, more particularly applicable to electric railways," communicated by Siemens & Halske, Berlin, forms a convenient starting-point for such a narrative, as the Zossen experiments may be considered the latest link in the chain of development of the ideas enunciated in that patent.

It is pointed out in the specification that "the use of Volta inductors or secondary generators for transmitting electrical energy offers the advantage of enabling a much higher tension to be employed than is possible with transmission by continuous currents, so that considerable energies can be transmitted through great distances by means of comparatively small conductors while at the same time the regulation of the power of motion is capable of being effected much more easily."

About the method of using the transformers in connection with electric railways, the specification suggests either to place them on the carriages or at certain distances apart along the line of rails.

In the first case the primary coils are connected by rolling or sliding contacts to the conductor extending alongside the rails, which conveys alternate currents of high tension thereto; while in the second case the secondary coils of the transformers would supply low-tension currents to the working conductor and thence to the motors on the carriages. As motors, dynamo machines that can produce continuous currents are recommended, and various methods of regulating them are described. The results obtained with such motors at that time were, however, not very encouraging, chiefly on account of the high frequency of the currents employed, and no important practical steps were taken until the three-phase motors began to occupy the attention of electrical engineers.

In March, 1892, Mr. Wilhelm von Siemens gave instructions to have a short experimental line constructed at the works of Siemens & Halske in Charlottenburg, and to try a 20-H.P. three-phase motor on it. The line was 360 m. long, with a curve of 40 m. radius and 70 m. long near its centre, the whole line being practically level. The current was supplied by a 50-H.P. three-phase machine, type R. 32/26, and between two terminals of the same a difference of potential of 500 to 600 volts was kept constant. At the end of July the motor-car was finished, and it was successfully tried on the 2nd of August, when loaded with 3,000 kg. At starting the motor was connected triangle fashion, and afterwards star fashion, running 1,400 revolutions per minute when the car was travelling at a speed of 22·5 km. per hour. The movement was transferred from the motor to the wheels by worm gear at the rate of 11 to 1.

Encouraged by the results, Messrs. Siemens & Halske formally applied, on October 29, 1892, to the Government for permission to equip from 40 to 50 km. of some Imperial railway near Berlin, in order to investigate experimentally the possibility of working the ordinary railways by means of electricity. They proposed to place transformers along the line, from which a low-pressure current would be supplied to the cars, and they explained their desire for such a long line by their intention to run the cars at a speed of from 60 to 70 km. per hour. On November 12, 1892, the Government declared its readiness to take the proposal into serious consideration after the experimental line had been inspected by experts. Their visit took place on the 2nd December, but on the 22nd December the application was declined, as the experts had not been satisfied with the method of collecting the current from the conductor along the line.

In the experimental line two overhead wires were used, the rails forming the third conductor, and the Government experts, as well as some of the engineers of Messrs. Siemens & Halske, considered such a system as inapplicable to full-sized railways. The consequence of this attitude was another long pause in the development, until five years' later, when Mr. Wilh. von Siemens initiated further experiments, in which, however, high-tension currents were to be supplied to the car. His view was that, for great distances, the weight of the conductors had to be kept as low as possible, and that they would, for this reason, not be suitable to carry heavy currents ; consequently the tension had to be kept as high as circumstances would permit in order to allow sufficient energy being transmitted to the car.

A waste piece of land near Gross Lichterfelde was placed at the disposal of Messrs. Siemens & Halske by the parish, and they built a short line, about 1,800 m. long, of normal gauge, in 1898, equipping it with three overhead conductors for three-phase current of either 750 or 2,000 or 10,000 volts. At first the conductors were carried by insulators, each fastened to a movable wooden arm, and the current was collected by a horizontal bar, turning round a horizontal pivot and pressed by a spring from above against the conductor. When the speed of running was increased, these horizontal bars jumped at the

insulators and caused so much sparking that this arrangement had to be abandoned.

In rebuilding the line the three conductors were placed vertically one above the other, at a distance of 1 m., and the insulators to which they were attached were supported by an elastic cord stretched between the two ends of a channel iron bent in the form of an ellipse and fastened to the poles. The collectors were also modified, each consisting of a horizontal arm, turning round a vertical pivot, and carrying a vertical bow sliding along the conductor, a spring pressing the arm against the conductor. This arrangement was eventually found satisfactory for the highest speeds attained.

While it was possible to settle by the experiments on this short line a suitable form of collector and a reliable construction of the overhead conductors, it became obvious that for trials at greater speeds the assistance of the railway department of the Government was indispensable. In the course of negotiations to obtain this, the scope of the proposed trials was widened in so far that the co-operation of other firms was secured by the formation of the "Studiengesellschaft fuer elektrische Schnellbahnen," on October 10, 1899. This Syndicate consists of the Deutsche Bank, Delbrück Leo & Co., National Bank, Jacob S. H. Stern, A. Borsig, Phil. Holzmann, Friedrich Krupp, v. d. Zypen & Charlier, Allgemeine Elektrizitäts Gesellschaft, and Siemens & Halske.

The War Office placed their single line between Zossen and Marienfelde at the disposal of the Syndicate, and the President of the Imperial Railway Office became its Chairman. Each year the Syndicate has published a report of the trials of the preceding year, and all the data given in this paper are taken from these official reports, unless another source of information is specially mentioned.

The permanent way of the military line consisted of rails weighing 33·4 kg. per m., placed on iron and partly on wooden sleepers, and its condition was such that no greater speed than 80 km. per hour was allowed on it. In the first instance this was improved by relaying about 800 rails of 12 m. each, increasing the number of sleepers by 4,000 and adding broken stone ballast to the extent of 4,000 cub.m. This work was finished and the line, 23 km. long, ready for the trials on September 3, 1901, when the official inspection was satisfactory. At the same time electric contacts, to be actuated by the wheels, were placed at 500 m. distance from each other all along the line, and a registering apparatus at Mahlow Station was connected to them, so that the speed of the cars could be verified there.

The overhead conductors along the line were constructed by Siemens & Halske practically in the same way as the line at Gross Lichterfelde, with a device added to earth the line in case a conductor should break. At every insulator a metallic loop, about 30 cm. in diameter, extending horizontally towards the pole, is connected to the conductor, and a vertical copper wire passes through the centre of the loops, the copper wire being efficiently connected to the running rails and through them to the zero point of the three-phase generators, the rails being in addition connected to metal earth-plates at intervals of

1 km. Any interruption of a conductor brings it, therefore, at once into contact with earth, and prevents any accident by shock from the falling conductor. The efficiency of this arrangement was tested, both intentionally and by an accident, when the conductor fell on an official, but in both cases the earthing served as an absolute protection. The line is fitted at every km. with means of adjusting the strain, kept at about 1,000 kgs., and with lightning dischargers of the horn pattern. At a distance of about 1 km. from Marienfelde (km. 8·5) the feeding line from the generating station Oberspree, 13 km. distant, and built by the A.E.G., is joined to the line along the railway by a main switch.

Two carriages were built for the trials by v. d. Zypen & Charlier, of Cologne, constructed and fitted as corridor carriages in accordance with the rules of the German Railway Union. One of these cars, called "A," was furnished with its electrical outfit by the Allgemeine Elektricitäts Gesellschaft, and has been described by Mr. Lasche as stated above, while the other was fitted out by Siemens & Halske, and has been described by Dr. Reichel (*Elektro-technische Zeitschrift*, 1901, p. 671); in the reports the latter is called "S." Both cars carry the collectors, tested and approved of in the experiments of Siemens & Halske at Lichterfelde, with this modification, that in the "A" car each collector is carried by its own standard, while in the "S" car one standard carries all the three collectors. There are two groups of three collectors on each car. These cars were delivered on the experimental line in the beginning of September, 1901, and at first were drawn by locomotives so as to ascertain whether all their parts, especially the brakes and springs, were properly adjusted, and to study the mechanical behaviour of the collectors and conductors. Observations were also made as to the relative movements of the bogies and the carriages.

A final inspection was made on the 1st of October, and the permission to start running the cars by electricity was given on the following conditions:—

1. The trials may be commenced at a speed of 100 km. per hour. This may afterwards be increased to 120, 140, and 150 km. per hour, and subsequently at increments of 10 km., provided that before increasing the speed an official inspection shows that the permanent way, the rolling stock, and all other apparatus have given no trouble at the last speed.
2. Level crossings are to be closed all along the line before runs at more than 100 km. per hour are commenced, and proper catch-nets should be fitted under the conductors at the level crossings.
3. Experiments should at once be made to ascertain whether the electric instruments of the State Railway and of the Military Railway are in any way affected by the working of the electric cars or by any breaking of the conductors.
4. The time table for the runs is to be agreed with the Direction of the State Railway, running alongside the Military Railway, and the stationmasters from Marienfelde to Zossen are to be

advised on what days trials at speeds of more than 100 km. per hour are to take place.

5. The conductors must not be charged with electricity, apart from the time table, except at times sanctioned and announced to the Railway authorities by the Syndicate with a view of trials on the shunting rails.

At the trials the following rules and regulations had to be observed :—

(*a*) By permanent way officials :

1. The trials and electric tests take place only between 8.0 a.m. and 11.30 a.m. Except during this time, the main switch at km. 8·5 must be open.

   It is to be kept under lock and key, which is in the custody of the representative of the Syndicate.
2. Due notice of the time of the trials is to be given to all stations, Marienfelde to Zossen, and to all officials, including navvies, and no work is to be carried on during that time which might occasion contact with the conductors, nor is anybody allowed during that time to remain directly underneath the conductors or to lean against the posts.
3. As soon as the departure of a trial-car has been announced by gong signal, all gates at level crossings have to be closed and the officials have to remain outside the gates until the trial-car has passed.
4. If a conductor breaks during a trial, nobody should touch the fallen ends until reliable advice has been received that the current has been cut off. Should the conductor break during the time the current is off, the ends should be placed out of the way of the ordinary traffic, and notice should be given to the inspector.
5. If any irregularity of the posts or of the conductors is noticed, the inspector should at once have this put right, or cause the Syndicate to remedy the defect.
6. The permanent way between Marienfelde and Zossen is to be carefully inspected every day after the close of the trials, and any important irregularity is to be reported to the inspector, and no further trials must be run until the permanent way has been repaired.
7. To the stations, to the inspectors, and to the guards of level crossings a copy of the pamphlet, "First Aid for Accidents Caused by Electricity," is to be handed.

(*b*) For trial runs :—

8. When trials at a speed exceeding 100 km. are to be run, the representatives of the Military Railway and of the State Railway at Marienfelde have to be informed the day before.

9. On the days of the trials the main switch at km. 8·5 may be closed after 8.0 a.m. The representative of the Syndicate will permit the conductors to be charged when all work on the cars has been finished and all other preparations are complete. He then, with the consent of the engineer in charge of the respective electric company, will have the collectors brought into contact with the line, after a signal by a loud gong has been given in the shed.
10. As soon as the conductors are charged, nobody is allowed on the roof of the cars, and after the collectors are in contact with the line no further work must be done on the cars in connection with their electric fittings or with their bogies. Offenders against this rule to be removed from the shed, and will not be readmitted.
11. Should it become necessary, after the conductors have been charged, to work at the bogies or at the electric apparatus of a car, the collectors are to be carefully removed from the conductors and locked in that position in such a manner that no unauthorised person can move them.
12. Due care must be taken that the line and the level crossings are properly guarded before a run at a speed exceeding 100 km. per hour is commenced.
13. A Commissary of the Military Railway, the representative and at least one other member of the Syndicate, the engineer in charge, and a fitter of the respective Electric Company, the driver on duty, and the car inspector, should be present during each trial run.
14. The apparatus for starting and stopping the car must only be handled by the engineer-in-charge or by the driver.
15. A portable telephone is to be carried, so that in case of accidents a communication with the adjacent stations can be established with the help of the two lowest wires of the military telegraphs.
16. Before the commencement of each run the representative of the Syndicate and the engineer-in-charge will settle the speed and the brake-trials of the run.
17. At each trial sand and water, for extinguishing fire, are to be carried, together with such tools as may be wanted for slight repairs.
18. When the run is interrupted owing to a defect observed on the car, the collectors have to be removed from the conductors before an investigation takes place.
19. During the run the driver should note any places where the car does not run smoothly, and should inform the representative accordingly.
20. Should a fuse melt at the generating station, Oberspree, it should at once be replaced, but if it blows again nothing further should be done until telephonic communication has been established.
21. After completing the trials for the day the car-inspector should

minutely inspect the car and remedy any defects. Particular attention should be paid to the state of the axles, the tyres, the bearings, the springs, and all parts of the pneumatic and hand brakes. A similar inspection of the electrical apparatus is to be carried out by the engineer-in-charge of the respective electric Company, and the conductors along the line are to be examined by an engineer of Siemens & Halske.

22. In the car a copy of the pamphlet "First Aid for Accidents Caused by Electricity" is to be exhibited, and all notices concerning the touching of apparatus, entering the cars, etc., are to be strictly followed.

On the 3rd and 4th of October, 1901, the conductors along the line were officially inspected and tested under pressure, and on the 7th of October the electric current was for the first time turned on to the cars.

The Technical Committee of the Syndicate had settled on the 24th of September that the trials should be undertaken in such a manner as to ascertain:

1. The highest safe speed on the line.
2. The proper construction of the permanent way.
3. The most advantageous construction of the car.
4. The most suitable electrical outfit.
5. The amount of energy at the various speeds.
6. The cost of working.

To obtain the necessary data, each car has been fitted with the following instruments:—

1. A speed indicator for the driver.
2. A speed-registering apparatus.
3. An acceleration indicator.
4. A voltmeter.
5. An ammeter.
6. A wattmeter.
7. A phase indicator.
8. A pyrometer.
9. Air-pressure indicators.

The speed indicator registers the kilometres per hour, and is checked by the speed-registering apparatus on the car and by the instrument at Mahlow station, where the position of the car is indicated every 500 meters by the wheel contacts along the line. Of the greatest importance are the observations in connection with the brakes, both as regards the time and the distance taken to bring the car to a standstill after it has attained certain speeds. At the generating station in Oberspree, suitable instruments for registering volts and amperes were connected to the feeder, so as to check the apparatus on the cars.

Four sets of trials were to be run:

1. Starting and braking experiments up to a speed of 100 km. per hour.
   The generating station to supply current at 25 periods and the motors to receive current only long enough to attain the prescribed speed, when the current is to be cut off and the brakes are to be applied.
2. Running at an equal speed, with current of 25 periods, first from station to station and afterwards along the whole line, with resistances in circuit so as not to exceed the prescribed speed.
3. Similar experiments as under 1 and 2, but with currents of higher periods for speeds from 100 to 130 km. per hour.
4. Running with currents of 45 periods at speeds exceeding 130 km. per hour.

The two cars were to be used on alternate days, and no increase in speed was allowed unless everything had worked satisfactorily at the last speed.

On October 8, 1901, the "S" car made its first run between the car-shed and km. 10·5, but while the current was on, the signalling apparatus of the State Railway and of the Military Line were sufficiently affected to require the construction of metallic returns along the whole line. This was finished in time for the regular runs of both cars to commence on the 14th of October, and they were continued until the 30th of November, with the exception of twelve days during which the permanent way had to undergo extensive repairs.

During these trials the cars ran about 3,000 km., of which 2,200 km. were under current, and for 800 km. the cars were pulled by locomotives before any current was used. The first two sets of experiments were carried out according to programme, and dealt with speeds up to 130 km. per hour, and they were principally utilised to ascertain the rate of acceleration and the data of braking. During the third set the speed was gradually increased until the "S" car reached a speed of 160·2 km. per hour on the 5th of November, while the railway officials made an inspection of the line in accordance with the regulations governing the trials. Even at a speed of 140 km. the running of the cars became irregular owing to the condition of the permanent way, and at higher speeds the rails were bent and their level was so much disturbed that the speed of the subsequent runs had to be restricted to 130 km. per hour. It was, however, possible to make valuable measurements of the energy required, and the working of the collectors and conductors could be observed with currents of 48 periods and 13,500 volts.

About the behaviour of the various component parts the report of the Syndicate enters into great detail, of which a short summary only is given. At the generating station the steam dynamo and transformers worked quite satisfactorily, and supplied current of 25 to 50 periods and 6,000 to 14,000 volts. The feeder consists of four con-

ductors, each of 50 sq. mm. section, the fourth conductor connecting the running rails to the zero point of the two transformers. The conductors along the line, constructed as described above by Siemens & Halske, have given no trouble whatever even in heavy rain or hoarfrost.

One of the most important problems, namely, to ascertain how large quantities of energy can be transferred from a standing conductor to a rapidly moving car, has been successfully solved by the construction of the conductors and of the collectors, both of which were the outcome of the experiment at Gross Lichterfelde. Both carriages, built by Van der Zypen & Charlier, ran in a very satisfactory manner, and ran steadier at a speed of 120 to 130 km. per hour than an ordinary corridor train carriage at 90 km. per hour. At higher speeds the irregularities of the permanent way made the running dangerous. In the two articles mentioned above the electrical arrangements of the two cars are described in detail.

The report of the Syndicate makes the following observations :—

(*a*) It considers the switching arrangements of the "S" car more complicated than those of the "A" car, and suggests for both cars that it should be possible from either end to set both groups of collectors simultaneously.

(*b*) The transformers in both cars are cooled by air and have worked well during the trials.

In car "S," after running 230 km. in succession, necessitating 14 accelerations to a speed of 120 km. per hour, the temperature of the transformers was only 25° C.; they were therefore considered sufficiently large to stand long runs, especially as they worked well with 12,000 to 13,000 volts. On the other car the transformers were much lighter, but they were never overheated, only on the 19th of November a primary coil was short-circuited by a current of 12,000 volts. After that date currents of no more than 8,000 volts were permitted, so that the point could not be settled whether the transformers on this car could be used for long periods with high voltages.

(*c*) Each of the motors on both cars is designed for 250 H.P., the "A" car motors taking current at 435 volts, and the "S" car motors 1,150 volts, while the pressure in the secondary circuit is 650 volts when standing still and during acceleration. No difference in running was experienced, although the motors on the "S" car are rigidly fixed to the axles of the wheels, while the motors on the "A" car are carried by the bogie frame and drive by an arrangement of springs. The report prefers the latter arrangement, and suggests trying a third method—driving the wheels by connecting rods.

(*d*) The switches and resistances present another feature in which the electrical arrangements of the two cars differ; on the "A" car liquid resistances were employed, regulated by pumps, while metallic resistances were carried on the "S" car. Both arrangements gave no trouble during these trials. The metallic resistance switches are more complicated than the others but they work faster. Of great importance are the results obtained while accelerating and during the retardation of the cars. The acceleration varied with the demand on the generating

station and the motors, as was to be expected. To obtain a speed of 100 km. per hour the distances travelled varied from 2,000 to 3,200 meters, and the times from 138 to 220 seconds. These figures correspond to an average acceleration of 0·13 to 0·2 m. per second, and correspond to 700–1,000 H.P. As the motors are capable of exerting up to 3,000 H.P. during acceleration, this might have been increased correspondingly, but the generating set was not powerful enough to supply the necessary current. For trains intended to travel long distances without stops the rate of acceleration is, however, of less importance than the action of the brakes on which the safety of the service depends. Both cars were fitted with a Westinghouse quick-acting brake, hand brakes, and an electric brake acting by reversing the currents through the motors. The "A" car had, in addition, an accumulator battery, the current from which could be sent through the three-phase motors. A great many trials with these brakes are reported, which are not important enough for recording in detail as the brakes were not satisfactory, but a few curves are reproduced in Fig 1, showing the results. In Fig. 2 the decrease of speed is shown when the "A" car was left to itself after attaining a speed of about 106 km. per hour respectively. The wind at the time was W.N.W. and had a speed of 11·4 m. per second ; it offered therefore less resistance during the run from Marienfelde to Rangsdorf than in the opposite direction.

Very numerous observations were made about the consumption of energy both in the generating station and on the cars especially during the last set of runs. For this purpose readings were taken at the switchboard in the generating station every ten seconds of the volts, amperes and watts, and the periodicity of the current was checked by the number of revolutions of the generating set. On the cars amperes and volts were read at intervals of from 15 to 30 seconds. The measurements at the station were the most accurate, as the instruments there were not exposed to the vibrations unavoidable on the cars. After making the observations they had to be corrected, as the instruments were only correct at a certain periodicity.

Numerous further measurements were taken and the following table gives the average result of the power required at a constant speed :—

Car.	Speed.	B.H.P.			Efficiency of electrical outfit.		Consumption of steam. Kg. per B.H.P. per hour.	
	Km. per hour.	Measured at feeding point.	Measured at car collector.	Calculated from speed.	Car by itself.	Car and conductors.	At car wheels.	At flywheel of steam engine.
					Per cent.	Per cent.		
"A"	118	478	455	397	87	83	5·84	4·6
"S"	115	431	405	341	84	79	6·12	

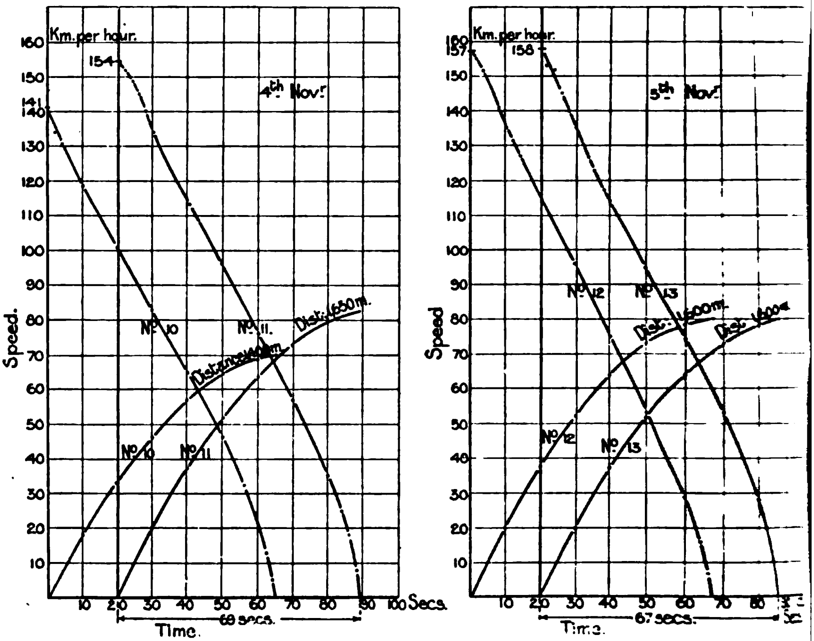


FIG. 1.—High-speed Experiments.

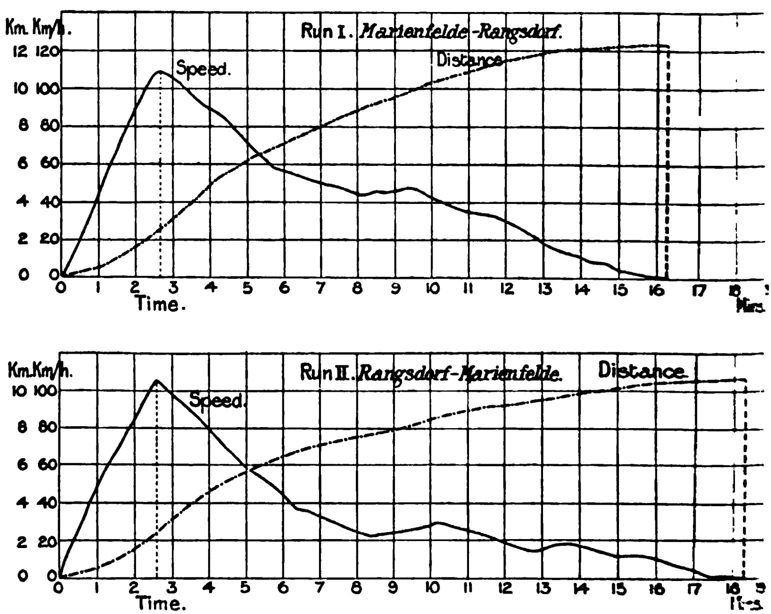
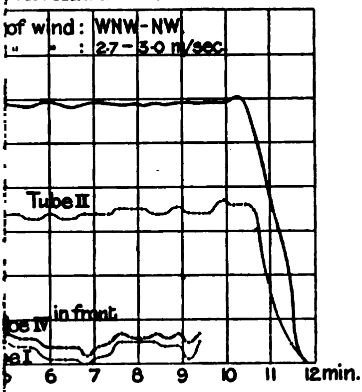


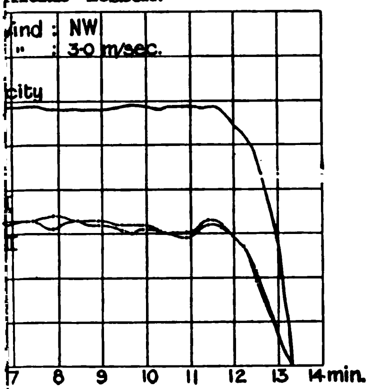
FIG. 2.—Car "A."

Curves showing retardation on November 28, 1901.

ssen-Marienfelde.



nfelde - Zossen.



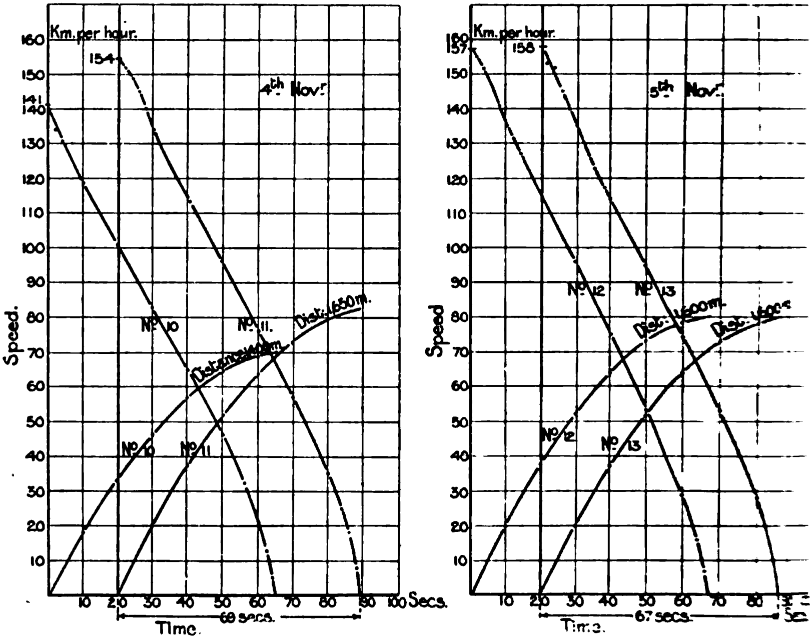


FIG. 1.—High-speed Experiments.

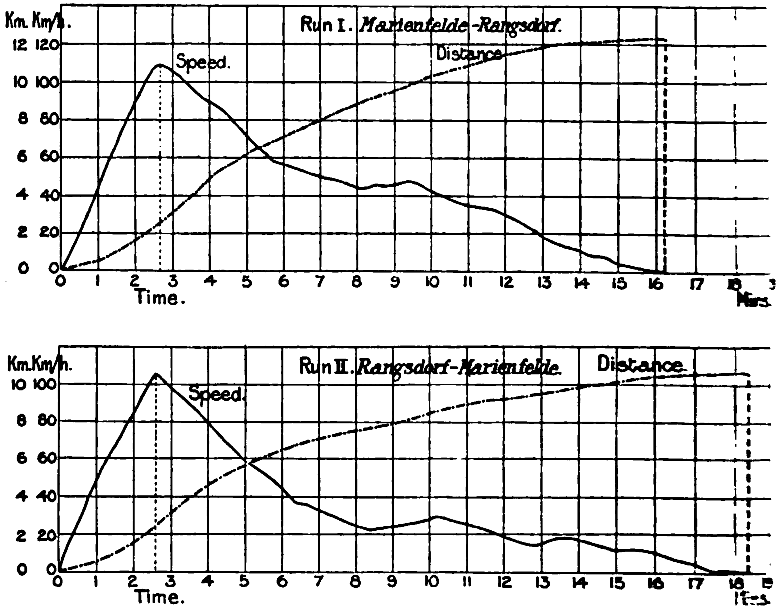
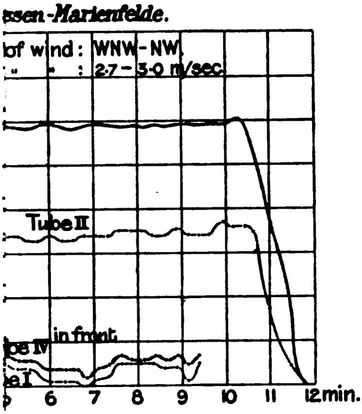
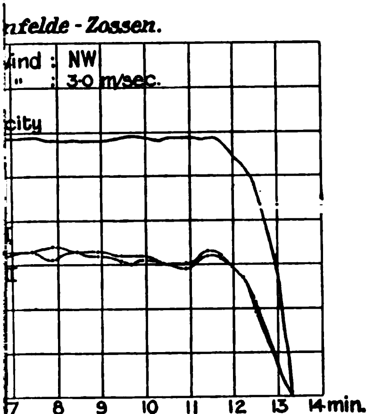


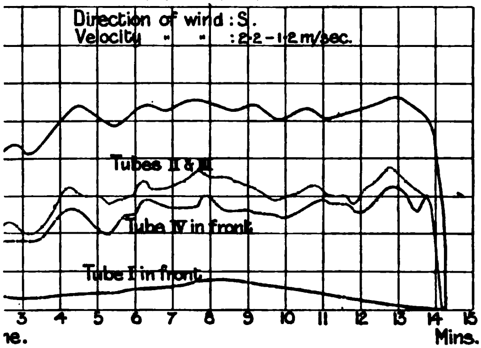
FIG. 2.—Car "A."

Curves showing retardation on November 28, 1901.

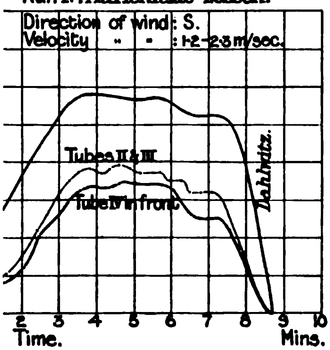

ssen-Marienfelde.
of wind : WNW-NW
" " : 2·7 - 3·0 m/sec.
Tube II
Tube IV in front
be I
6 7 8 9 10 11 12 min.


nfelde - Zossen.
wind : NW
" : 3·0 m/sec.
city
7 8 9 10 11 12 13 14 min.

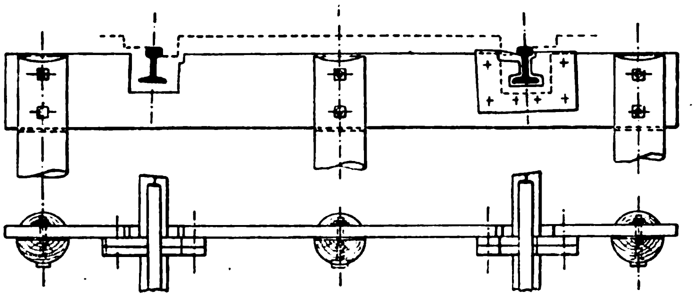
Run II. *Zossen-Marienfelde.*



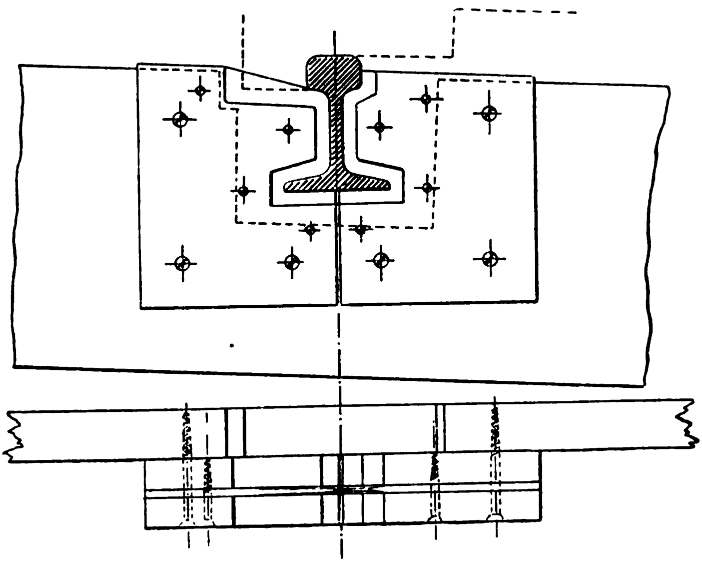
Run IV. *Marienfelde-Zossen.*



The report does not consider these figures reliable enough for commercial deductions, partly because the instruments were not properly calibrated for the varying periodicity of the current, partly because the motors in both cars were working very much below their rated output.



M. 1:20



M. 1:5

FIG. 5.--Apparatus for indicating the movements of the rails.

For the purpose of observing the air resistance at the various speeds openings were made in various parts of the car bodies and short brass tubes inserted. These tubes were connected by indiarubber tubes to a row of pressure indicators consisting of pairs of communicating glass tubes about 5 mm. in diameter partly filled with water. An adjustable

scale was fitted to each indicator divided into millimeters, so that the difference in the water level of the two tubes could be observed at the various speeds. Four such openings were made at each end of either car, two of which were near the centre and the other two at the sides, as indicated in the diagrams of Figs. 3 and 4.

Preliminary trials proved that the position and the form of the opening of the brass tubes have no influence on the result, and this made it possible to compare the pressure all over the front of the car with the pressure in the centre, independent of the varying speed of the car. In addition, straight tubes, up to 3·4 m. long, were fitted to explore the pressure of the air in front of the car, and these observations showed that a cone of uniform pressure exists in front and at the back of the car, the apex of which was about 3 m. distant from the car. The "A"

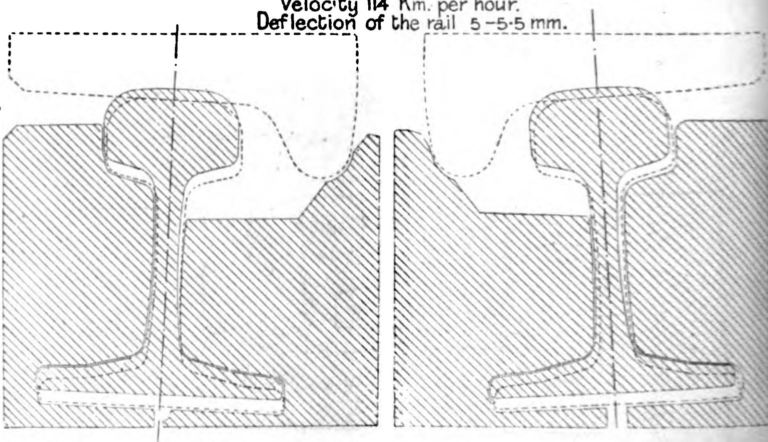


FIG. 6.—Diagram of the displacement of the rails on November 30, 1901, at 15·8 kilometres.

car, as the diagram shows, has well-rounded corners, while the "S" car has its ends in the shape of truncated cones. The pressure on these was very much smaller than in the centre, and sometimes even negative owing to the influence of the wind. Some openings were also made along the sides of the car and occasional observations showed that speed had very little influence on the pressure indicated, when the brass tubes ended flush with the sides of the car, and that the direction of the wind has much more effect. The figures 3 and 4 show the results of observations made during several runs of both cars.

Combining all the results the report considers that up to a speed of 150 km. per hour the pressure may be calculated by the equation $p = 0{\cdot}07\, v^2$, when v is the velocity in meters per second and p is the pressure on a surface of 1 sq. m., at right angles to the direction of the motion. The number of observations were, however, insufficient to

determine the best form for the end of the cars. Another set of observations was made to determine the extent of the movement of the rails, when the cars were passing at various speeds. For this purpose measuring apparatus were set up at various points of the line, which are shown in Fig. 5. Each of these consists of three strong posts, about 1¼ m. long, rammed into the ground, one in the centre and one on each side of the rails, to which a strong board is fastened with its upper edge a little below rail level and with suitable openings cut to permit the rails to pass through. Near each rail two short boards are bolted to the plank, between which a lead plate is supported. This is cut in two and fitted accurately against the rail, the edges touching the rail being sharpened. It is evident that any movement of the rail will bend these edges back and thus leave a permanent record of the greatest movement of the rail. The result on one set of lead plates is shown in Fig. 6, and a summary of the principal observations is the following :—

Distance between sleepers.	Material of sleepers.	Ballast. MOTOR CARS.	Speed Km. p.h.	Depression of rails in mm.
850 mm.	wood	sand	108	2·0—2·5
850 ,,	wood	sand	114	3·5—5·0
780 ,,	wood	stones	145	6·0—6·5
780 ,,	iron	sand	114	5·0—5·5
780 ,,	iron	sand	135	6·0—6·5
730 ,,	iron	sand	123	6·0—7·0
		MILITARY TRAINS.		
850 ,,	wood	sand	70–80	1·5—2·0
730 ,,	iron	sand	70–80	4·0—

From these experiences the conclusion was drawn that the permanent way had to be thoroughly reconstructed before speeds exceeding 120 km. per hour could be safely investigated.

As the military trains run only at considerable intervals, at a comparatively low speed, the existing signalling apparatus had to be supplemented by distant signals about 2 km. from the stations, and some difficulty was also experienced in seeing sufficiently far ahead in rainy weather. It is, therefore, suggested to repeat the signals on the car by visual and by audible means, which should also indicate when the apparatus is out of order. In addition it is recommended to cut the current off in the sections which a car has just left.

In conclusion, the first report states that, thanks to the care exercised by the firms supplying the cars and outfit, to the cautious and reliable execution of all the electrical work, to the careful maintenance of the permanent way and its appurtenances, and to the conscientious observation of all the precautionary measures, no mishap or damage of any kind has occurred during the trials. No psychological effects on the drivers or passengers, attributable to the high speeds, have been noticed. Although it has not been possible to obtain reliable data for judging

the economical aspect of this question, some valuable technical information has been gained. In the first place, the experiments have shown that it is possible to collect high-tension currents even in unfavourable weather from overhead conductors at double the speed of the present express trains. Both the conductors and the collectors have worked so satisfactorily up to the present that their efficiency at higher speeds may be safely assumed. Three-phase motors have shown themselves

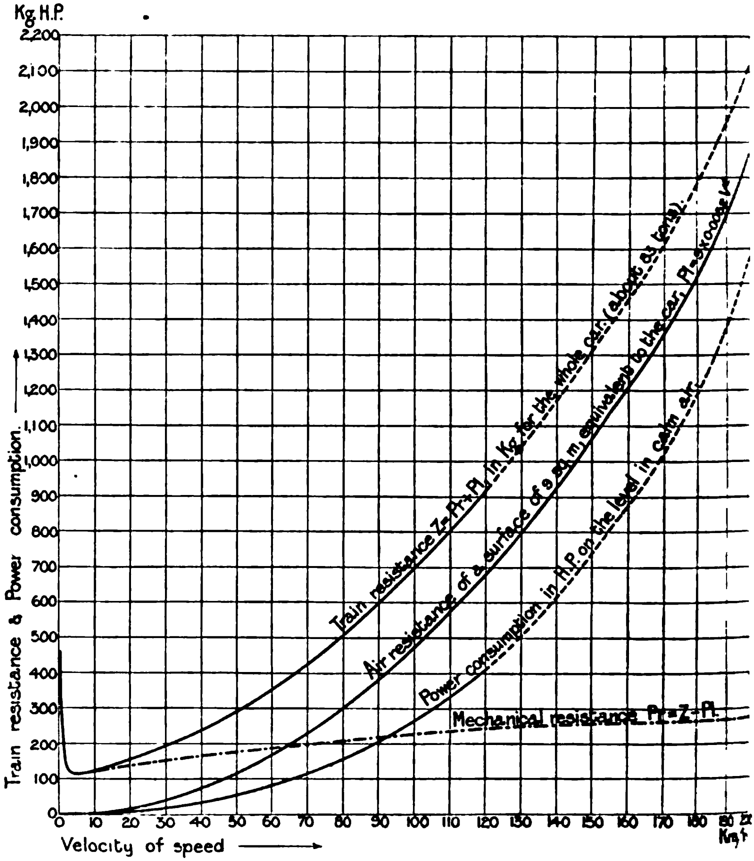


FIG. 7.—Train resistance and Power consumption of the High-speed Cars.

reliable, and their overheating has been prevented by suitable ventilation. It has, however, not been possible to decide whether it is preferable to fix the motor on the axle or support it wholly by springs; nor can it be safely said whether fluid or metallic resistances are the more suitable. The brakes have not been powerful enough for the high speeds. An alteration of the existing arrangements, and the adoption of an efficient electric brake appears to be imperative.

Generally speaking, the first year's trials have served principally to find out the best methods of making observations, and to determine which are the most suitable instruments for obtaining trustworthy information. Basing further experiments on the knowledge thus gained, it is certain that it can be ascertained whether the cars, their equipment, and all other outfit are suitable for regular traffic on main lines at a speed of 160 km. per hour, and whether still higher speeds are practicable, especially from an economic standpoint.

Originally it had been the intention to resume the experiments in 1902 on the lines laid down at the commencement, and to increase gradually the speed of the cars until a speed of 200 km. per hour had been attained. It was, however, not possible to relay the permanent way in time, and in consequence of this the authorities would not allow a greater speed than 125 km. per hour. The time was therefore

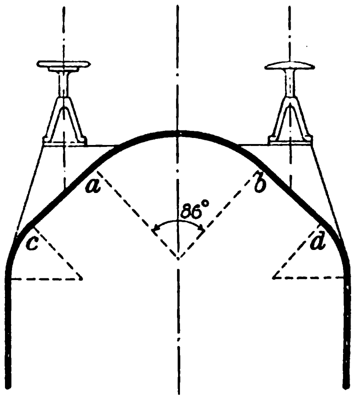


FIG. 8.

utilised for determining more accurately the resistance of the cars at various speeds, the power required for propelling them, and the losses of energy in the feeder and the conductors. In addition to this, further experiments were made with the brakes, and alterations in the structure of the cars were considered, to insure steady running at high speeds; the movement of the rails was also observed during the trials.

The second report describes the experiments in great detail, and the following are the principal results ascertained by their help :—At first attempts were made to determine the resistance of the cars direct by pulling them at moderate speeds by a locomotive, to which they were attached by a dynamometer. It was found, however, that owing to the great weight of the cars, and owing to the irregular pull of the locomotives, no steady curves could be obtained, nor was the success greater when the cars were attached to a goods train. Somewhat better results were achieved by the employment of a three-phase loco-

motive, but the curves were still too irregular to be accepted. Nothing remained but to revert to observing the time each car took to come to a standstill after attaining a certain speed, and the distance it covered during that time, due account being taken of all differences in level. The smallest curve on the line has a radius of 2,000 m.; it was therefore not necessary to consider the curvature in the calculation: but very careful measurements of the air resistance were made by means of tubes projected from the cars in the way already described, and in the end a small correction was found necessary in the formula for air resistance, which was altered to $P = \cdot 0052\ V^2$, and the resistance of the cars was found to be equal to the resistance of 9 sq. m.

In Fig. 7 the final results of the traction resistance of the cars are represented by four curves showing the total resistance for a car

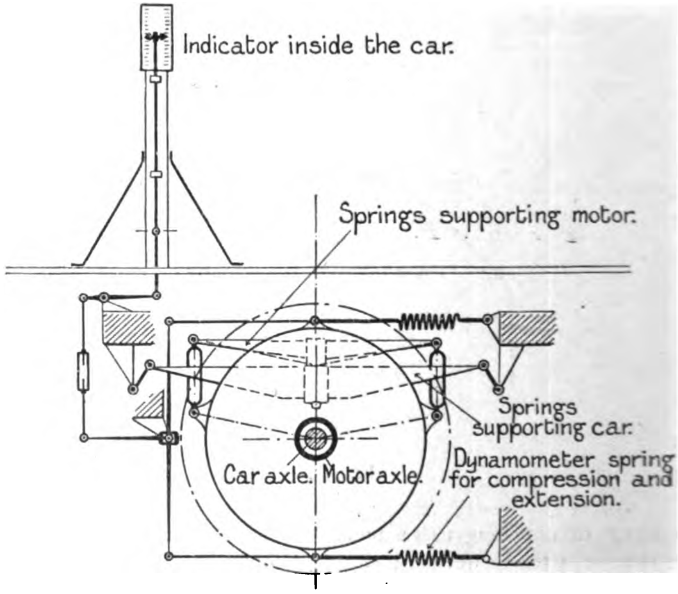
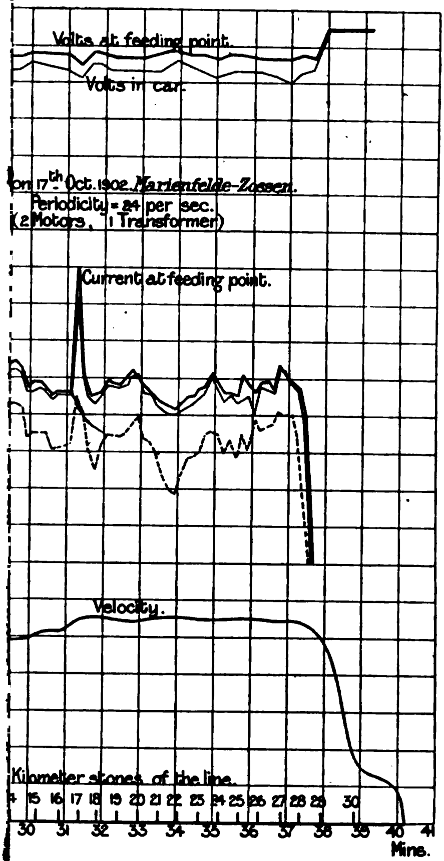


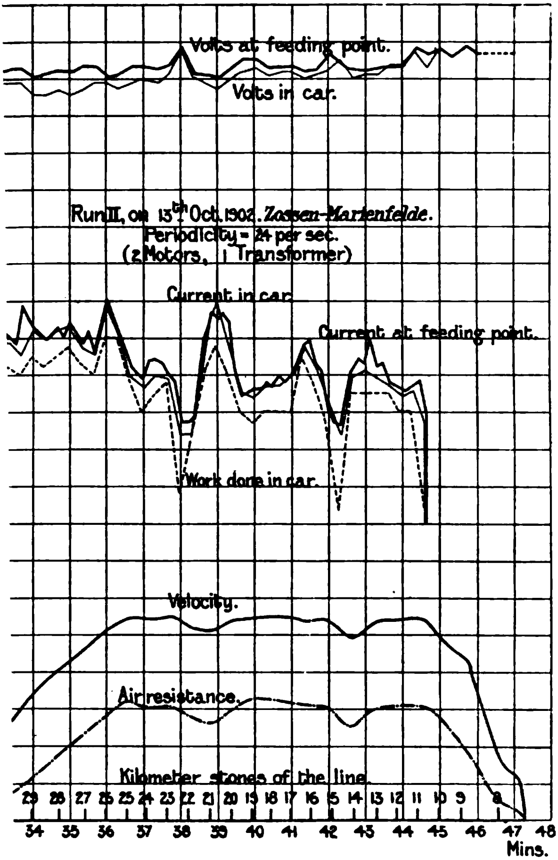
FIG. 12.

N.B.—The shaded parts are fixed points either on the Car frame or on the Bogie.

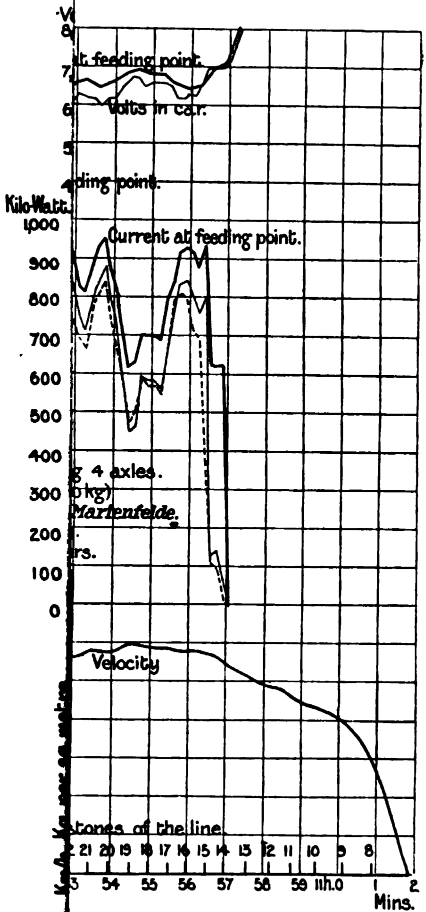
weighing 83 tons, the air resistance of a surface of 9 sq. m. being the equivalent of the air resistance of a car, the H.P. required on the level with no wind, and, by the difference of the first and second curves the resistance due to mechanical friction. It is at once apparent, from this diagram, that at high speeds the air resistance is by far the most important factor, and that the proper shape of the car has to be very carefully determined.

From their experiments the Studiengesellschaft draw the conclusion that the front of the car should be a rather steep paraboloid. Owing to the necessity of arranging the cabin of the driver in front,


Volts at feeding point.
Volts in car.
on 17th Oct. 1902. Marienfelde-Zossen.
Periodicity = 24 per sec.
(2 Motors, 1 Transformer)
Current at feeding point.
Velocity.
Kilometer stones of the line.
15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
30 31 32 33 34 35 36 37 38 39 40 41
Mins.


Volts at feeding point.
Volts in car.
Run II, on 13th Oct. 1902. Zossen-Marienfelde.
Periodicity = 24 per sec.
(2 Motors, 1 Transformer)
Current in car.
Current at feeding point.
Work done in car.
Velocity.
Air resistance.
Kilometer stones of the line.
29 28 27 26 25 24 23 22 21 20 19 18 17 16 15 14 13 12 11 10 9 8
34 35 36 37 38 39 40 41 42 43 44 45 46 47 48
Mins.

).



t feeding point.
Volts in car.
ding point.
Kilo-Watt.
1000
900
800
700
600
500
400
300
200
100
0
Current at feeding point.
g 4 axles.
0 kg)
Marienfelde.
rs.
Velocity
stones of the line.
21 20 19 18 17 16 15 14 13 12 11 10 9 8
54 55 56 57 58 59 11h.0 1 2
Mins.

and providing buffers and drawbars, it is not possible to carry this out in practice, but the nearest approach to the correct form is suggested to be a cylindrical front, extending for 86°, then plain surfaces which join the sides of the car by easy curves, as represented in Fig. 8. Very careful measurements were made as to the amount of energy required, and a measuring station was established at the feeding-point, to avoid the calculations of the losses in the feeder. The ammeter and wattmeter at this station were connected direct to the high-tension circuit, to avoid the use of transformers and to make them almost independent of periodicity and of difference in phase. In the cars the instruments were joined to the same phase as at the feeding-point. In spite of all precautions, however, the readings were not all reliable, especially in wet weather.

The measurements are divided into two groups: one to determine the energy during acceleration, and the other to measure it at constant speed. In both cases the cars were sometimes running by themselves, and sometimes pulling trailing cars. It will be noticed that the acceleration is not very great, but this was the consequence of the generating set not being powerful enough to supply more energy. Compared with the theoretical amount of energy required to give the cars the same acceleration, the figures of the table show an efficiency of about 45 per cent., due, no doubt, to the losses in the starting resistances; but for long-distance travelling the period of acceleration is almost negligible.

In Tables A and B the results of these experiments are summarised, and diagrams in Figs. 9, 10, and 11 give some details of runs with and without trailers. An attempt was made to measure the turning moment of a motor direct by fitting on car "A" a special apparatus represented in Fig. 12. In-

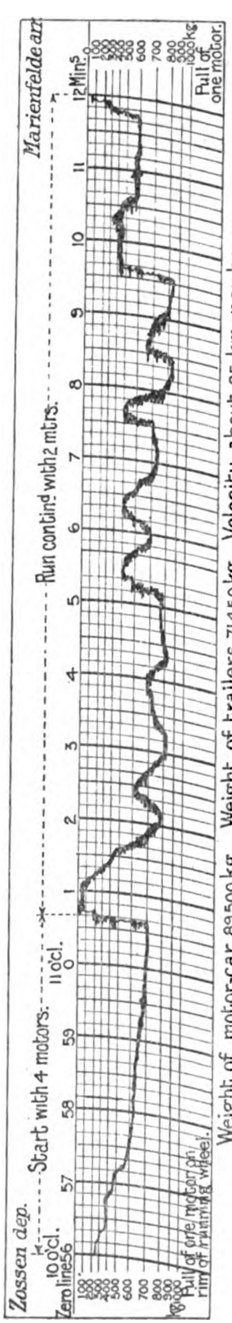


FIG. 13.—Diagram of the turning moment of the Motor observed in Car "A" during run No. 4 on November 8, 1902 (with 4 six-wheeled Trailers).

stead of attaching the motor rigidly to the frame, it is held by springs, as shown diagrammatically, and the movement of the springs is transmitted by suitable levers to a registering indicator in the interior of the car.

The instrument was calibrated by weights, and gave useful results when a resistance was inserted in the secondary circuit of the motor, but of course the direct comparison between the indicated turning moment and the electrical readings is thereby prevented. The diagram Fig. 13 shows the turning moment during a run of car "A" on the

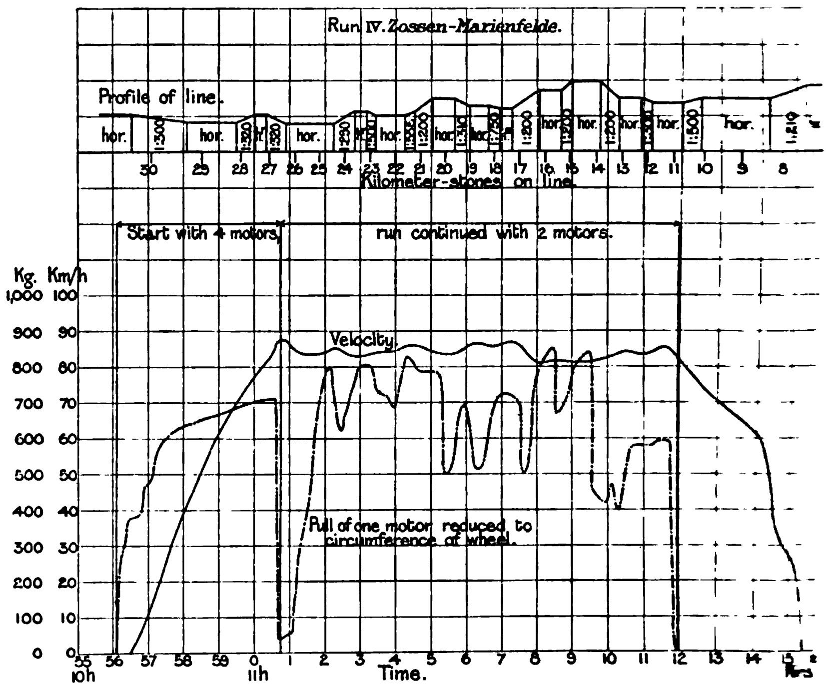


FIG. 13A.—Trial runs of Car "A" with 4 in. wheeled Trailers on November 8, 190[illegible]

Pull, Velocity and Profile of Line.

8th of November, and the curve, Fig. 13A, is drawn in accordance with these indications. About the measurements made to ascertain the loss in feeders and conductors, nothing need be said, as no novel features with regard to them are disclosed in the report. Nor need the brake experiments be described, as they were again unsatisfactory, and eventually it was considered advisable to alter the whole of the braking arrangements. A good opportunity for doing this was afforded by the reconstruction of the bogies, which became necessary to ensure the steady running of the cars during high speeds.

In the new bogies the following points were to be observed :—

1. The wheel-base is to be increased from 3·8 to 5·0 m.
2. The bogie frames are to be constructed with simple *Z* girders.
3. The bearing springs are to be connected by balancing levers, and are to be visible and easily accessible throughout their whole length.
4. The car body is to be supported at four points on each bogie.
5. The centre pin of the bogie is to be movable for a distance of 30 mm. in every direction.
6. The motors are to be connected to the axles by springs.
7. The brakes are to be reconstructed as shown in outline by Fig. 14, which explains itself.

During the trials the bending of the rails was measured in the same way as in the previous year; but as the speed of the cars had been

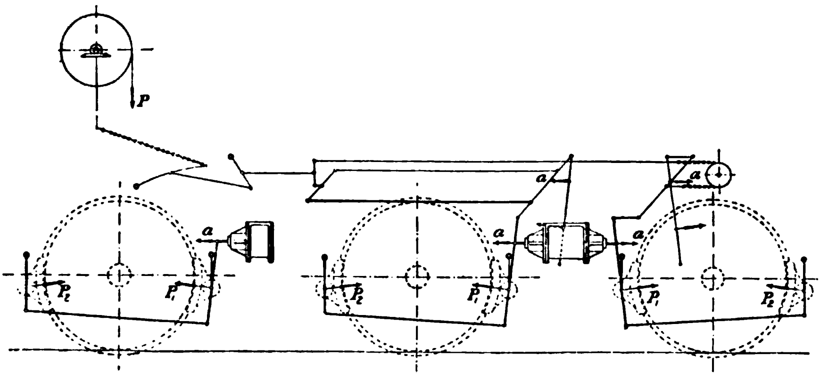


FIG. 14.

restricted, no abnormal observations occurred and no extraordinary repairs became necessary.

When the trial runs of the high-speed cars had been completed, some further experiments were made with a three-phase locomotive built by Siemens & Halske, and the Studiengesellschaft comments on them in a separate report. In this case they say that the high-speed cars have proved suitable for their work as far as their mechanical and electrical outfit is concerned, but their weight is too great and the proportion of their dead weight to the paying load is not favourable. The trouble with the permanent way and the very high power required during the acceleration period were a consequence of this weight, and for economical high-speed traffic it should, if possible, be diminished so as to load the axles only sufficiently for the necessary adhesion. It would not be possible to effect this object by altering the construction of the car or by lightening its mechanical outfit without endangering its safety. It is therefore necessary to try to diminish the weight of the electrical apparatus. This may be done by removing the transformers from the

TABLE A.

Average Value of the Electrical and Mechanical Measurements taken during Acceleration.

No. of Runs.	Number of Motors Working.	Total Weight of Train in Tons.	Distance in Meters.	Falling Gradient average %.	Average Acceleration m/sec.	Final Speed, km/hour.	No. of Periods per sec.	At Feeding Point. Amp.	At Feeding Point. Volts.	At Feeding Point. K.W.	At Collector of Car. Amp.	At Collector of Car. Volts.	At Collector of Car. K.W.	At Collector of Car. H.P.	Remarks.
CAR A.															
5	2	89·5	4,430	0·30	0·08	88·6	20·6	51·2	5,662	—	50·0	5,376	358	487	Car alone.
2	4	89·5	3,950	0·84	0·12	97·5	20·8	—	5,165	—	74·2	4,835	446	606	" "
6	2	89·5	7,930	0·54	0·07	106·0	24·0	51·1	6,383	—	50·1	6,024	407	553	" "
2	4	89·5	4,550	0·57	0·11	102·5	25·0	—	6,740	—	76·0	6,360	535	727	" "
3	4	188·4	8,700	0·61	0·07	113·3	25·0	101·0	6,253	880	—	—	813	1,105	Car drawing three passenger cars.
CAR S.															
9	2	77·9	2,744	1·11	0·13	91·2	20·8	52·6	5,472	—	51·8	5,257	394	535	Car alone.
9	2	77·9	4,294	0·68	0·12	105·6	24·0	51·1	6,290	—	50·5	5,950	434	590	" "
6	4	159·6	5,583	0·60	0·11	116·7	25·0	108·2	6,237	1,010	105·6	5,938	928	1,261	Car and two passenger cars.
1	4	193·4	8,300	—	0·07	115·0	25·0	110·0	6,140	988	107·0	5,450	855	1,160	Car and three passenger cars.

Observations taken in Autumn, 1902.

TABLE B.

AVERAGE VALUE OF THE ELECTRICAL AND MECHANICAL MEASUREMENTS TAKEN DURING PERIODS OF RUNNING AT CONSTANT SPEED.

No. of Runs.	No. of Motors Working.	Total Weight of Train in Tons.	Average Speed km/hour.	No. of Periods per sec.	At Feeding Point.			At Collectors of Car.				Efficiency of Electrical output %.	Power exerted on wheels.		Remarks.
					Amp.	Volts.	K.W.	Amp.	Volts.	K.W.	H.P.		H.P.	Pull in Kg.	
CAR A.															
4	2	89·5	95	20·6	43·4	5,835	—	42·1	5,543	246	335	82·7	277	788	Car alone.
2	4	89·5	96	20·8	—	5,450	—	64·0	5,190	247	336	69·7	234	660	„ „
5	2	89·5	107	24·0	45·6	6,460	—	43·8	6,089	302	410	86·4	354	892	„ „
2	4	89·5	113	25·0	—	6,830	—	71·5	6,390	365	496	79·1	392	938	„ „
2	4	188·4	117	25·0	84·7	6,647	694	—	—	644	875	87·1	762	1,760	Car and three passenger cars.
CAR S.															
8	2	77·9	92	20·8	36·7	5,781	—	34·5	5,619	197	268	84·0	225	660	Car alone.
8	2	77·9	106	24·0	39·2	6,447	—	36·8	6,162	283	385	86·5	333	850	„ „
4	4	159·6	117	25·0	69·2	6,937	566	65·0	6 685	499	679	85·5	580	1,330	Car and two passenger cars.
1	4	193·4	118	25·0	81·5	6,700	713	75·0	6,425	680	925	87·7	810	1,840	Car and three passenger cars.

Observations taken in Autumn, 1902.

TABLE C.

Runs, at Constant Speed, of Three-phase Locomotive with One Trailer.

Date—June, 1902.	Run No.	No. of Periods per sec.	Weight of Train in tons.	Time of Measurements in seconds.	Speed in km. per hour.	Average at Feeding-Point.			Average Value of cos ϕ Calculated.	Average Power at Feeding-Point.	Weight of Trailer in Kg.
						Amp.	Volts.	K.W.			
23	I.	30	52·25	810	70	10	7,250	76	0·60	At 70 Km/hour 91 K.W. = 124 H.P.	12,250
	II.	30	52·25	240	70	11	7,200	105	0·75		
24	I.	30	57·68	390	65–70	9·5	7,200	71	0·59		17,680
	II.	30	57·68	350	65–70	15	7,150	137	0·74		
25	I.	40	52·25	790	85	12	8,200	136	0·79	At 86 Km/hour 184 K.W. = 250 H.P.	12,250
	II.	40	52·25	800	86	18	8,100	222	0·86		
	III.	40	52·25	760	86–88	13	8,250	150	0·81		
	IV.	40	52·25	820	86	18·6	8,150	225	0·86		
26	I.	47	70·75	410	101–102	20·5	10,650	322	0·84	At 102 Km/hour 293 K.W. = 398 H.P.	30,750
	II.	47	70·75	390	102	18·5	10,850	285	0·285		
	III.	47	70·75	310	101·5–102	18	10,770	270	0·81		
	IV.	47	70·75	360	101·5–103	19	10,770	290	0·82		

car and placing them along the line, or by dispensing with them altogether. In the first case a double set of conductors is required, increasing the losses and the capital expenditure. It is therefore preferable to employ motors which are capable of utilising high-tension currents.

With a view of trying the possibility of using such motors on the high-speed cars, Messrs. Siemens & Halske built two motors of approximately the same outside dimensions as those on car S, but suitable for working with 10,000-volt currents, and fitted them each to a four-wheeled bogie with a wheel-base of 3·25 m. The car body, 12·5 m. long, is of the

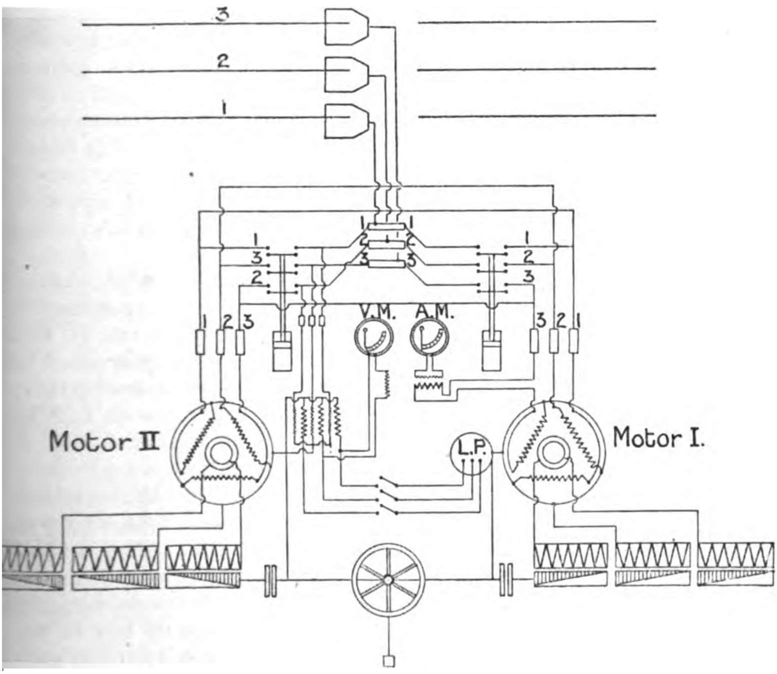


FIG. 15.

L.P. = Air Pumps.

usual shape for electric locomotives, and in its centre is a driver's cabin 4 m. long by 2·8 m. wide by 2·3 m. high. In the iron boxes on either side of it are the starting switches and resistances, and on the top it carries the collecting gear, which is like that of car "S." The motors are suspended from the bogie frames after the manner of tram motors, driving the axles by a gearing of 1 : 2. Between the car body and the wheels are two sets of springs, and provision is made for a slight lateral movement relative to the bogie.

The diagram (in Fig. 15) of the connections shows that there are separate switches, moved by compressed air, for each direction of running, a small transformer to supply low-tension current to the air-

pump motor, and mechanical switches for the resistances which are actuated by a hand-wheel in the driver's cabin, geared to a horizontal shaft.

Some difficulties were experienced in obtaining readings of the measuring instruments on the locomotive of sufficient accuracy, so that finally only the measurements at the feeding-point were taken into consideration.

The trial runs were started on June 23, 1902, with 7,250 volts, and this voltage was gradually raised until the locomotive successfully pulled a trailer on June 26th with just over 10,000 volts.

Some of the details of the measurements taken during these runs are given in the Table C.

It is at once apparent that the efficiency of the locomotive is much greater than that of the cars at the trials in 1901, for the reason that its motors were working nearer to their rated output.

Another reason is the absence of a transformer, so that a comparison at an output of 400 H.P. shows that the locomotive required for this at 10,800 volts, and $\cos\phi = 0{\cdot}85$, an average current of 19 amperes, while the cars at 6,300 volts and $\cos\phi = 0{\cdot}5$ consumed about 53 amperes. The losses in the conductors along the line are therefore 2 k.w. in the case of the locomotive, and 17 k.w. in the case of the cars.

In conclusion, the report considers that the trials have proved the possibility of building motors for three-phase currents of 10,000 volts, used direct without transformers. It is mentioned that the motors and the gearing have worked without giving any trouble up to a speed of 100 km. per hour, and that the working without transformers makes it possible to reduce the weight of the high-speed cars from 92 tons to 76–78 tons, an achievement which will materially diminish the cost of working and the wear and tear of the permanent way.

In the interval between the experiments of 1902 and those of last year, the permanent way of the line was renewed throughout, and now it is equal to that of a German first-class main line. The rails are 12 m. long, Vignoles pattern, standard profile 8; they weigh 41 kg. per meter, and are supported by 18 sleeper bedded in stone ballast. As a matter of precaution, guard-rails were added all along the line, but it was evident, when they were carefully examined after the trials, that even at the highest speeds their service had never been required. Owing to the losses in the feeder and to the reduced speed of the generating sets, the acceleration could not be raised beyond 0·15–0·18 m. per second, although the motor on the cars would have been capable of developing more power than they actually did. The bogies of both cars were altered in accordance with the experience gained in previous trials, as requested by the Syndicate.

In the "A" car the switching arrangements were altered so that the motors can be started one after the other instead of simultaneously, and further ventilation for the motors has been provided. The electrical arrangements of the "S" car remain exactly as they were made in the first instance; the motor casing, however, is now supported by springs from the bogie-frame, so that only the rotating parts of the motors remain rigidly fixed to the axle.

An arrangement for measuring the turning moment by means of registering the pressure exerted by the casing on a piston working an oil manometer has been added to one of motors of the "S" car, and also devices for diminishing the pressure on the brakes with diminishing speeds. All the exhaust openings of the Westinghouse brakes have been united by a common pipe on which two exhaust valves are fitted. One of these can be manipulated by the driver and the other is under the control of an electrical contrivance, the circuit of which is closed automatically by a pendulum weight when the retardation exceeds a certain rate. These additions had been found necessary as the pressure on the brake blocks at the highest speeds had to be equal to 200 per cent. of the weight of the car, which at lower speeds would skid the wheels. For both cars the collectors were modified by dividing their horizontal arm into three parts, connected by springs, with a view of diminishing as much as possible the weight of the part receiving the blows caused by irregularities of the conductors and damping their effect further by sub-dividing the mass which has to be accelerated. In addition, the balancing wings which counteract the pressure of the wind on the collector arms were reconstructed with great care. A model of such a collector, kindly lent by Messrs. Siemens & Halske, is on the table.

With regard to the general arrangement of the electrical outfit, the running of the cars at high speeds showed that the weights have to be distributed symmetrically on both sides of the car, in order to prevent excessive swaying. For this purpose balancing weights had to be added in the "A" car because the transformers had not been placed exactly symmetrically in the first instance. The actual runs began on the 15th September with the "S" car, on which day a speed of 150 km. was reached, and the improvement in steadiness owing to the alteration of the bogies was most marked. During the following days the speed was gradually increased in the manner laid down in the original program, until on the 6th October a speed of 201 km. per hour was attained with a current of 46 periods and 14,000 volts. It should be noted that in the curves with a radius of 2,000 m. the speed of the cars was restricted to 165–170 km. per hour, so as to avoid any danger. This point is in so far important as it shows that most of the existing main lines would be unsuitable for speeds greatly exceeding those of the present traffic.

One of the engineers, who was in the "S" car during the run, gives the following details :—

"After examining the car and all the apparatus, the current was turned on until each of the motors was supplied with 350 amperes, corresponding to 2,300 k.w. for the car.

"The feeding point, about 1 km. distant, was passed at the speed of 80 km. per hour; 2 km. further, 120 km. per hour was indicated; and at the first curve of 2,000 m. radius the speed was 170 km.; Mahlow, 7 km. from Marienfelde, was passed at 185 km. per hour.

"Still the car is running quite smoothly and all measurements can be noted down with greater comfort than in an ordinary express train.

"Keeping the power at 2,300 k.w. the last resistances are gradually cut out and the speed increases to 195 km. per hour. Suddenly a sounding blow is heard against a window of the driver's cabin. It is no mishap to the car, but a bird is killed which has been overtaken by the car. At last 1 km. before Rangsdorf the indicator passes the 200 km. per hour mark, and for the space of another km. this speed is maintained with an expenditure of 1,400 k.w. Then the brakes have to be applied, so that the car enters the second curve of 2,000 m. radius with a speed of 165 km., and arrives at the terminal station of Zossen. 8 minutes after leaving Marienfelde.

"An examination of the car shows it to be in absolute order; its front covered with bees, gnats, and other insects, which appear as if smashed by a heavy weight—naturally, as the air-pressure rose to 210 kg. per square meter. The recording speed indicator showed that the maximum speed had been 200·8 km. per hour."

After this memorable run further systematic measurements of air resistance, retardation, etc., were made, and the "A" car also began running. It made a record of 210·2 km. per hour on the 28th October. with a periodicity of 47·5 per second, all restrictions as to speed in curves being suspended on that occasion. During this run the car swayed so much that one of the conductors was broken, and fell by accident on the foot of an official. The earthing device acted, however, so promptly that the man received no electric shock whatever. On the same occasion one of the transformers in the generating station was slightly damaged, and in consequence the Syndicate would not allow more than about 45 periods per second for the subsequent trials.

TABLE D.

HIGH-SPEED RUNS.

Date, 1903.	Car.	Periods per sec. p	Corresponding speed $V = \frac{1{\cdot}25 \times \pi \times 3600}{3} \times p$.	Max. speed during run V_1.	Slip $\sigma = \frac{V - V_1}{V}$.	Remarks.
			Km. per hour.	Km. per hour	Per cent.	
28 Oct.	A	47·5	223·84	210·2	6	
11 Nov.	A	45·3	213·94	196·0	8·4	
	S	„	„	208·0	2·8	
17 Nov.	A	40·2	189·4	182·0	4·0	
	S	„	„	184·0	2·8	The strength of the Soda Solution in starter had been increased.
25 Nov.	A	45·5	213·5	204·7	3·9	
	S	„	„	207·3	2·75	

Table D gives a summary of the most notable runs, comparing the theoretical speed, which depends on the number of periods, the diameter of the wheels, and the number of poles (3 pairs), with the actual speed, from which the slip can be calculated. The slip of the motors in the "S" car was uniformly 2·8 per cent, so that it would

TABLE E.

Average Value of Measurements taken during Acceleration.

Date, 1903.	Level above ordnance datum.		Acceleration.			Final speed Km./h.	Periods per Sec.	At Feeding Point.			At Collectors of Car.						Wind.		
	Start.	Finish	Time in Sec.	Distance in Metres	Average rate.			Amps.	Volts.	K.W.	Amps.	Volts.	K.W.	Cos ϕ	K W. hours.	H.P.	Direction.	Velocity	
Car "A" (Weight 94,000 Kg.)																			
Oct.	48·14	42·8	360	13.450	0·162	210	48	132	10,410	—	132	10,110	2,040	0·88	205	2,770	E.	1·6	Without bow fitting.
Nov.	40·05	42·3	393	12,580	0·123	174	40	112	9,840	1,570	112	9,000	1,440	0·825	162	1,960	W.	4·8	Ditto.
„	48·14	45·1	220	5,380	0·197	156	36	118	8,910	1,420	118	8,910	1,390	0·765	98	1,890	E.	3·5	Ditto.
„	48·14	42·1	360	10,100	0·134	174	40	146	8,750	1,840	146	8,670	1,760	0·80	186	2,320	S.S.W.	3·2	With sleeping car (44,300 Kg.).
„	48·14	39·6	270	8,540	0·185	180·5	40	126	9,925	1,650	124	9,810	1,590	0·756	126	2,160	N.N.E.	2·6	With bow fitting.
„	48·14	47·35	280	8,520	0·178	180	40	118	9,850	1,600	117	9,705	1,570	0·80	131	2,140	N.N.E.	2·6	Without „
„	40·05	47·6	365	12,280	0·154	205	46	126	10,980	1,935	126	9,840	1,760	0·82	186	2,390	S.W.	3·2	With „
Car "S" (Weight 93,400 Kg.)																			
Oct.	40·05	47·0	374	14,250	0·153	206	46	134·4	12 015	2,320	134·2	10,160	2,130	0.9	220	2,900	S.S.W.	4·9	
„	40·05	42·2	410	12.450	0·123	180	40	113·5	9,380	1,520	112·8	8,050	1.415	0·9	161·2	1,925	S.E.	3·3	
Nov.	48·14	42·14	350	10,050	0·114	162	36	125·2	9,120	1,650	124·8	8,900	1,572	0·815	152·6	2.135	E.S.E.	3·3	With sleeping car (44,300 Kg.).
„	48·14	48·98	230	6,280	0·196	162	36	120·0	8,865	1,525	119·5	8,730	1,490	0·825	95·2	2,020	E.S.E.	3·3	
„	48·14	42·2	400	15.100	0·145	209	46	134·3	10,630	2,090	134·0	10,240	2,010	0·845	223	2,730	S.W.	3·2	
„	48·14	48·2	265	7,595	0·178	170	40	115·5	9,190	1,530	114·0	9,000	1,490	0·839	109·6	2,030	S.W.	5·9	
„	48·14	48·0	280	7,650	0·181	170	40	118·0	9,040	1,550	117·7	8,785	1,520	0·853	109·8	2,070	S.W.	5·9	

TABLE F.

Average Value of Measurements taken while Running at Constant Speed.

Date, 1903.	Average Speed Km h.	No. of Periods Per Sec	At Feeding Point.			At Collectors of Car.					Power exerted on wheels calculated for level, calm and cos ϕ = 183.		Remarks.
			Amps.	Volts.	K.W.	Amps.	Volts.	K.W.	Cos ϕ.	H.P.	Per Run.	Average.	
Car "A" (Weight 94,000 Kg.)													
22 Oct.	172·5	40	100	9,855	1,335	100	9,360	1,285	0·795	1,745	1,389		
24 "	177·5	40	97	10,490	1,320	96	10,035	1,045	0·630	1,420	1,168		Without wedge-shape bow fitting.
14 Nov.	163·0	36	85	9,640	1,035	84	9,180	955	0·715	1,320	1,114		
14 "	163·5	36	81	9,460	980	80	9,110	935	0·740	1,270	1,034	1,074	
17 "	175·0	40	109	9,870	1,575	108	9,360	1,460	0·835	1,985	1,496		
17 "	168·5	40	113	9,670	1,590	(113)	9,300	1,450	0·800	1,970	1,589	1,544	With sleeping car (44,300 Kg.).
19 "	178·5	40	94	10,400	1,250	92	10,030	1,205	0·758	1,640	1,263		Without bow fitting.
20 "	182·0	40	93	10,930	1,170	89	10,560	1,080	0·655	1,470	1,363		
20 "	180·0	40	92	10,700	1,240	91	10,275	1,185	0·733	1,610	1,265	1,314	With " "
20 "	182·0	40	93	10,500	1,350	90	10,200	1,160	0·730	1,575	1,511		
20 "	181·0	40	94	10,300	1,300	93	9,900	1,230	0·780	1,610	1,360	1,435	Without " "
Car "S" (Weight 93,400 Kg.)													
26 Oct.	180·0	40	103·1	9,630	1,425	102·1	9,000	1,380	0·860	1,875	1,535		Car by itself.
13 Nov.	163·0	36	102·8	9,600	1,382	101·8	9,000	1,269	0·800	1,720	1,322		With sleeping car (44.300 Kg.).
13 "	161·0	36	109·0	9,200	1,450	108·0	8,600	1,380	0·857	1,875	1,329	1,325	
13 "	165·0	36	86·0	9,700	1,060	85·4	9,310	1,000	0·724	1,355	1,164		
13 "	165·0	36	83·2	9,600	1,065	83·0	9,100	1,010	0·770	1,372	1,155	1,159	Car by itself.
14 "	165·0	36	88·0	9,400	1,100	87·4	8,900	1,040	0·770	1,412	1,203		
14 "	165·0	36	83·0	9,440	1,030	82·4	9,000	1,000	0·777	1,355	1,089	1,146	" "
23 "	168·8	36	85·4	10,150	1,100	83·5	9,700	1,040	0·740	1,412	1,287		" "
23 "	168·0	36	84·5	10,100	1,080	83·7	9,600	1,020	0·730	1,385	1,250		" "
26 "	172·0	36	87·4	10,250	1,140	86·9	9,420	1,080	0·702	1,465	1,179		
26 "	171·5	36	90·0	10,000	1,185	89·5	9,500	1,145	0·776	1,555	1,334	1,256	" "
26 "	171·5	36	87·0	10,050	1,125	86·5	9,540	1,070	0·750	1,453	1,166		
26 "	171·0	36	88·5	9,800	1,180	88·0	9,300	1,140	0·805	1,550	1,343	1,254	" "
26 "	171·5	36	85·6	[illegible]	[illegible]	84·2	[illegible]	1,050	0·770	1,425	1,140		
26 "	170·5	36	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,170	[illegible]	[illegible]	[illegible]	[illegible]	" "

have run up to 217·6 km. per hour if it had been supplied with currents of 47·5 periods per second. It is, however, of no great moment whether a few km. more or less were accomplished by one or the other car; the important fact has been successfully demonstrated that trains can be constructed and worked by electricity at about double the speed of the present express trains, on a permanent way not materially differing from that of a first-class main line, except that it would not be safe to allow curves having a smaller radius than 2,000 meters in parts of the line where the trains have to run at full speed.

In most cases it will, therefore, be necessary to build special lines for high-speed working, and no general rule can be established whether it would pay to do so.

Although the experimental cars carried transformers and were equipped with three-phase motors, there is no necessity that these features should be repeated in future. The trials of the locomotive in 1902 have shown that motors can be built for working direct with current of 12,000 volts, and the 1886 patent foreshadows the possibility of using induction motors with single-phase currents, so that only one overhead line is required when the running rails are used for the return.

From the official report of last year's trial the Tables E and F have been compiled, giving data during acceleration and during running at constant speed. It was found that an ordinary express car could not be used as trailer at speeds exceeding 180 km. per hour owing to excessive swaying, demonstrating the necessity of having a long wheelbase for the bogies and a symmetrical distribution of weights so that all wheels carry equal parts of the weight. Retardation experiments confirmed the formula previously found for the determination of air resistance, $P = 0{\cdot}005\ V^2$, but it was incidentally mentioned by Col. v. Scheve that for calculating the resistance of the air to projectiles, the artillery officers used a formula of Newton's: $P = \frac{\Delta}{2g} V^2$, in which Δ is the weight of a cubic meter of air and V = velocity in meters per second. Taking the average value of $\Delta = 1{\cdot}293$ and expressing the velocity in km. per hour, Newton's formula becomes $P = 0{\cdot}0051\ V^2$, which agrees remarkably well with the formula deduced from the experiments.

In concluding their report about last year's trials, the Syndicate congratulate all those concerned on the successful achievement of the original problem, and they announce their intention of continuing the trials in order to test the endurance of the various apparatus and to investigate the question of employing single-phase motors.

As the generating station at Oberspree is at present so overloaded that no current can be supplied to the Zossen line, the Syndicate are examining, at present, projects for establishing actual high-speed lines

They give as an appendix to their report such a project for a line between Hamburg and Berlin, but time will not permit to go into that subject to-night.

It would, however, be very ungrateful to conclude this paper without expressing to the Syndicate and to the firms who carried out the trials the warmest thanks for their kindness and liberality in placing the results of their work at the disposal of this Institution.

Professor Silvanus Thompson.

Professor SILVANUS THOMPSON: There are a few questions that I wish to ask Mr. Siemens, which will perhaps supplement some of the points given in the paper. On page 900 he mentions an acceleration indicator, and I am curious to know what kind of an instrument that is. On page 911 there is a statement that connecting certain instruments directly to the high-pressure line makes them independent of the frequency. I would like to know exactly how we are to take that cryptic sentence. Mention was made of a car with four motors on it, two motors on each axle, and of a locomotive that had two motors only. I think in the case of the locomotive it was said that the switching-gear was so arranged that each motor could be switched in separately one after the other. What I wish to ask is whether experiments were included with one motor or two motors combined in cascade for getting acceleration at different rates. Lastly, I would draw attention to the discrepancy, which is probably entirely reasonable and capable of giving us further information, between the experience on this line and on the Central London line as to the trouble caused by the weight of the locomotive. Apparently in this case the trouble arose when there was not a separate locomotive, but where the motors were on a car which carried passengers; whereas on the Central London Railway the trouble arose when there were separate locomotives, which have been abandoned in favour of having cars with motors upon them. Wherein is it that experience has differed? Why has trouble been given in one case with one arrangement, and in the other case by the other? I am sure we shall all concur in thanking Mr. Siemens, and through him the Syndicate, for having laid before us these very valuable results.

Mr. de Ferranti.

Mr. S. Z. DE FERRANTI: I think the most noticeable thing brought before us in the paper is that it shows how much more opportunity is afforded in Germany than in this country for making notable developments of great importance to the whole community. Of course the Government has no railways in this country, but in the case of Germany the Government has lent every assistance to a project of this world-wide importance, and I think that the example is most admirable. I do not think that the Government in doing this is doing anything in the nature of a charity; I think you might say that it is one of the duties of a Government to assist in the progress of industry in this way. It is also a great lesson to us, and shows how difficult it is for us to compete with this sort of thing, when another State is so liberal and far-seeing as to assist scientists and men of business to advance great undertakings of this kind and to obtain results which must be of immense value to the progress of the country. I think that is a thing we must carefully consider, and it is a pity it is not more widely known and appreciated in this country, so that it might come home to people, on whom it would have a good effect in altering their views as to their duties. With regard to the particulars given in the paper itself, they are all of the highest possible interest. The thing that it brings home to one's mind, however, is that the conversion of our existing railways in this country will not give the speed advantage that it should do. The curves are most serious upon the best lines. Take,

Mr. de Ferranti.

for example, the London and North-Western line between London and Manchester or Liverpool, upon which a splendid service of trains is run, which, in the case of the fast trains, run regularly at about a mile a minute consistently right through. That line, which is, I think, the finest in the country, would be very difficult for extra high-speed travelling. You have only to make an easy observation to see the effect of the curves on that line. When the sun is down, watch the shadow on the table by the side of the window; you will then see that there is not a straight run for any appreciable period of time; the shadow is continually shifting backwards and forwards: sometimes it seems as though the train were reversing its direction, so great is the angle of variation. The result is that I am afraid our best lines cannot benefit to the full extent that one would wish for in getting a really high speed of travelling. On the other hand, these experiments are of the greatest possible importance in connection with our railways, because they would enable us to maintain a very high average speed. Really the principal economies in fast railway travelling to-day are to be obtained by going up the grades at quite as high a speed as when you go down them—in fact, maintaining a very high uniform speed. With regard to the other points in the paper, there are so many, and the paper is so full of interest, that it is almost out of the question to discuss it, or say anything much to the point upon it, without much reflection and consideration. I hope that these wonderful results which have been obtained in Germany may be repeated to some extent in other countries which have not been so fortunate as to be able to originate them. I am sure we are exceedingly grateful for every detail of the valuable information which is furnished in this paper.

Hon. C. A. Parsons.

The Hon. C. A. PARSONS: I should like to ask a question of the author, in connection with this most interesting problem of high-speed travelling on railways. In the paper he mentioned that the air resistances are much the largest portion of the whole resistance, and exceed the rolling friction. Would it be possible by suitably modifying the form of the car to reduce the air resistance further than it has been, so that the power absorbed would be very much less. The air resistance of the axles with the motors and gear beneath the car must form a very large component, moving as they do so close to the permanent way. Could not provision be made for boxing in the motors, and still further reducing the resistance?

Mr. Patchell.

Mr. W. H. PATCHELL: Sir, while I listened to the paper I quite agreed with Mr. Ferranti, that it was a sad thing to have to listen to the result of these experiments made in Germany; but I think, at the same time, we must be glad that we have been able to import the results, like many other good things, without a prohibitive tariff. As regards the commercial aspect of High-Speed Railways, Mr. G. J. Morrison discussed that subject very ably after Mr. Bennett's paper,* and I think it is a pity that Mr. Aspinall, who was one of the first men in this country to make experiments as to the power taken by steam locomotives, is not present to help us with the discussion to-night.

* *Journal of the Institution of Electrical Engineers*, vol. 33, p. 530.

Mr. Patchell. About three months ago I travelled over this line, but in an ordinary train, and was much interested to know whether I was travelling over the actual metals which were used for the experiments; on looking out of the window I believed that we were running on the metals next to the trolley-wire posts. When I got back to Berlin I made inquiries, and was told that they were the actual metals. The jolting on that line made me rather think of running through Herne Hill, or a bit of the Midland Railway which is chiefly used for mineral traffic. I think if the engineers got the results that they have obtained on such a line it is very greatly to their credit; and if that line was made with a heavier road, more in accordance with the best English practice, then I think they would be able to take their readings on the instruments on the car with greater accuracy, to say the least of it. The psychological effects are not solely due to the speed; they are due, to a great extent, to the state of the permanent way over which the train is running. I have seen the A.E.G. liquid resistance at work, though not on a car, and it certainly is a very beautiful way of altering the speed; but when I saw the huge size that the resistance had to be made as compared with the motor, and that it required a little motor of its own to work the centrifugal pump, I rather wondered that they had taken such a cumbersome affair on one of the cars. I understand that the actual number of passengers which can be carried on the car is fifty, and it struck me that if it was loaded up with resistance of that sort it would be rather like the Heilmann locomotive, and the commercial efficiency would not be very great. The diagram of air pressures is not quite clear, probably because one has not had time to look into it. I suppose the little sketch at the top left-hand corner, is the plan of the "A" car, and the other is the "S" car. I wished to see what was the air pressure behind the car, because I think we might get some valuable information by comparing the wind pressure in front of the car and the wind pressure behind the car. The same lettering appears to be used for the tubes at each end of the car, and it is not at all plain to me at the moment as to what was the pressure behind the car. Such data have important bearing on the subject of the strength of bridges and structures against the wind, a question which is being gone into largely now. It may interest the members to know that the steam locomotive engineers are not going to sit down under these experiments. A German friend told me quite lately that the steam engineers are now building a locomotive the cylinders and cranks of which are arranged so that there is no vertical couple unbalanced and no horizontal couple unbalanced, so that it will neither "pound" nor "rock," and then they are going to see how far they can keep up with the electrical car.

Mr. Mordey. Mr. W. M. MORDEY: I would like to join in congratulating the German syndicate on giving an actual proof of the physical possibility of running a train electrically at a very high speed. That is not the least of the uses of these experiments. It appears, however, from the author's remarks, that it has been borne in on the minds of those who made the experiments that the three-phase system is not all that could be wished for either high-speed or low-speed electrical work. I came

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to that conclusion long ago, and gave my reasons for it. I have recently seen much to support those reasons. At Easter I visited an experimental railway at Oerlikon, where the one-phase system was being tried. I do not know whether I shall be in order in referring to those trials. They are, to me, of very great interest, perhaps partly because, with Mr. B. M. Jenkin, about two and a half years ago I read a paper at the Civil Engineers, pointing out the inherent drawbacks of a three-phase system for anything like comprehensive railway working, and advocating as strongly as I could the adoption of one-phase methods. I am glad to say that in several directions one-phase railways are now being experimented with. The public trials of the Oerlikon Company's system were conducted on the method first suggested thirteen years ago by Mr. Ward-Leonard, of America, who proposed to use a motor-generator on the train to transform from a high-tension one-phase current to direct current. One interesting thing about the experiment was the very simple collecting arrangement used. In our trips abroad, members will have noticed that the Siemens bow has been much used in tramway work. Recently when I was in Germany I found the Siemens bow was being displaced by the trolley wheel because of the wear of the conductor, the weight of the bow, and for other reasons, such as the formation of ice on the lower side of the trolley wires, which caused trouble in winter. That difficulty is avoided in the arrangement described by the author, where the current is collected from the sides of the wires. But the Oerlikon Company have gone further. Normally they collect by a light bow resting on the top of the wire, but it is pivoted at one end, so that it can collect either from the top or side or from under the wire, the bow following the wire through an angle of 180 degrees. When it comes to two wires, for crossing purposes, it simply runs under or over or on the sides of the two wires, and passes from one to the other without any difficulty at all. The motor of the Oerlikon motor-generator is an ordinary squirrel-cage induction motor of about 400 H.P. The line is supplied with 50-period alternate currents at about 13,000 volts, the stator of the motor being wound for 13,000 volts. It is wound also for 700 volts, so that if for any purpose, in a tunnel or anywhere else, it is desired to reduce the pressure, the same motor can be used at the lower pressure. The question of regulation and the use of resistances has been referred to, and Mr. Patchell has mentioned the great size of the resistance used on the "A" car. In the case of any car that depends on regulation by the use of a varying resistance, that resistance is a very serious thing for the whole system, quite apart from the loss of energy in it. In the Oerlikon Company's modified Ward-Leonard arrangement, the whole of the regulation is effected by varying the excitation of the dynamo of the motor-generator, and that only involves a resistance that does not occupy a square foot, and probably weighs only about 5 lbs. One problem which I have always thought of very great importance in electric railway work, particularly on lines with short runs, with the stations close together—conditions, perhaps, that hardly apply to the subject of the paper—is that of avoiding the great losses that take place at

Mr. Mordey. starting and stopping. Some time ago I examined the results obtained on the Liverpool Overhead Electric Railway. At Liverpool they have got the very best results in acceleration that have ever been obtained; they are accelerating and retarding at the rate of about 4 ft. per second per second. But on examining the actual curves that have been taken by Mr. Cotterell there, I find that only 25 per cent. of the energy delivered to the car is actually spent on driving it; 50 per cent. goes in heating the brake blocks, and another 25 per cent. goes in heating the resistances at starting. On the Oerlikon system there is no resistance loss at all; there is, however, a loss due to the use of a motor-generator, but this is much less than is inevitable with the use of resistances. But the arrangement has many advantages beyond that of getting rid of resistances and the loss in them: it gives a variable ratio gear, from starting with large torque and large current but small volts, up to running at full speed with high volts and small current, and all the time keeping on the alternate-current circuit a high power-factor. Mr. Huber took me over the line several times, and I was able to make some experiments. Although the conditions were not favourable to anything like accurate measurements—the line was only a kilometre long—it was quite possible to satisfy oneself that the variable-ratio effect was obtained satisfactorily. For example, we put a great load behind, and blocked the wheels, and tried to start until we had much more than the proper full working current on the motor, without getting more than one-third of the full current on the alternating-current motor itself. Another important thing, that is perhaps not dealt with effectively in any other system, is the possibility of braking by returning energy to the line instead of wasting it in heating the brake blocks. The experiments proved this very clearly. It was quite possible by a single movement of the regulator handle to reverse the field of the generator, and so cause the train motors to act as dynamos and to drive back on to the line—not merely to stop the locomotive quickly, but actually to drive it back again; it was like an air cushion or spring. I hope the wealthy, powerful and influential German syndicate will follow up the excellent and useful work it has done, and will add to our indebtedness by simplifying the electrical arrangements on some such plan as is being worked out by the Oerlikon Company, and by others, and that we shall have from the author a year or two hence a paper giving the results. I think that when we get simplicity of the outside system—the first essential for successful railway working—we shall be in a position to persuade railway directors to electrify their main lines of railway.

Mr. Smith. Mr. E. Wythe Smith: I should like to ask one or two questions, more especially with regard to the permanent way. Among the conclusions arrived at from experiment, the Syndicate decided that existing permanent ways were not suitable for high-speed railways. This I suppose applies to present Continental practice, and I do not think it necessarily follows that the best English main lines are not suitable to traffic of very much higher speed than at present. If I remember rightly, the last set of rails laid on the experimental line weighed about 82 lbs. per yard, and only 30 ft. rails were used. On our

leading railways 90 lb. rails are generally used for main lines, and in some cases 108 lb. rails are already laid. Instead of 30 ft. rails, 60 ft. rails are being used to a large extent. Thus so far as the weight of rails and number of joints, modern English practice appears to be quite sufficient. Mr. Smith.

With regard to the question of guard rails, although in one place the author said that on the curve the speed had to be reduced, yet later on he mentioned that on examining the line after the experiments it was found the guard rails had not come into operation. I should like to hear why it was necessary to reduce speed; whether on account of the shifting of the sleepers, or want of sufficient inclination of the track. Mr. Ferranti has referred to the line to Manchester; I am also well acquainted with the run to Liverpool, which is practically the same, at any rate as far as Crewe. I travel this line very often, and nearly always in one direction by the night train; I therefore have experience both sitting up and lying down. In running backwards and forwards to Russia I also know the German main lines fairly well, both sitting up and lying down. On the North German main lines they have the advantage of a good straight line, and fairly level country to go through, against our anything but straight runs or level country, yet I do not think the former permanent way will compare with our best English main lines, zig-zag though they are. An examination of the line will show that the guard rails on an English main line are usually well worn and bright. I understand the shape of the front of the car was a cylinder with a vertical axis; if this axis had been made slanting backwards towards the car so as to make the shape of the car more nearly approach a hemi-parabola in vertical section, seemingly a further improvement might have been made. The author referred to the repeaters which were employed to repeat the various signals on the car for the driver: I should like to know whether these were entirely successful, and to hear any further details of same. So many have been tried in England, and up to the present there are few if any which will stand the rough usage (almost abuse) they get in ordinary practice. On referring to the tables I notice that the movement of the rails was found to be much greater with iron sleepers than with wooden sleepers. This I have come across in India, and have always accounted for it as being due to the impossibility of getting an iron sleeper properly rammed. There is one other point on which I should like to ask for some information; I notice on the cars six-wheeled bogies were employed, but on the locomotive four-wheeled bogies. Were the middle wheels on the six-wheeled bogies "flanged" wheels, and if so, did they give any trouble? In conclusion, I should like to record my appreciation of the paper, and also of the work done.

Mr. H. L. LEACH (*communicated*): It would be very interesting if Mr. Siemens could give some particulars of the losses on open circuit with 5,000 and 10,000 volts pressure at the feeding point, viz., the energy absorbed between the generating station and the feeding point, and also the energy consumed to keep the overhead conductors charged. Mr. Leach.

Mr. E. KILBURN SCOTT (*communicated*): The active co-operation of Mr. Kilburn Scott.

Mr. Kilburn Scott.

the German Government with the Study Company in the trials which Mr. Siemens has summarised are an object lesson to the rest of the world, which cannot be too widely known, for it is Government in its widest and truest sense. The action of the parish authorities of Gross Lichterfelde in placing land at the disposal of Siemens & Halske on which to make the earlier and in one sense more epoch-making experiments is also most commendable. I doubt whether any Urban District, Parish, or Borough Council in this country would have been broad-minded enough to do likewise.

I was surprised to hear Mr. Mordey make the sweeping statement that the Continent was giving up the bow for the trolley. As a matter of fact all the latest undertakings, Cologne, Amsterdam, Vienna, etc., have kept to the bow after a thorough investigation of both systems. There may be a few isolated cases, but on the other hand I can refer to cases in the States where the bow has been adopted after a long trial of the wheel; and one of the very largest of the American street railway systems was so disatisfied with the trolley wheel that a sum of money was voted for the express purpose of investigating the claims of the bow. As a matter of fact, however, one does not need to go abroad for arguments, for surely the fact that over eighty per cent. of the accidents on electric tramways in this country are traceable to the trolley wheel jumping the wire is argument enough. For railway working, especially at high speeds, I think the bow is ideal, because it does not require any frogs or switches, and there is much less wear and tear on the wire and its supports; the overhead system can therefore be made lighter and cheaper. Mr. Mordey seems to be very enamoured of a new collecting device by the Oerlikon Co., which, although ingenious, hardly seems to fill the bill. For example, at high speeds there would surely be trouble in having to adjust the collector to the varied positions of the trolley wire, and in case the driver forgot this the overhead equipment and collecting device would be likely to get into a considerable tangle. In any case it is only suitable for a single wire, and with very high tension such as is employed at Berlin two wires would be necessary even if single-phase had been adopted.

It has been suggested that the Study Co. are dissatisfied with three-phase and have leanings towards single-phase, but I do not see any indication of this in Mr. Siemens' paper; and I certainly think it would be a step back if it is true. So far as the Oerlikon Ward-Leonard system is concerned, I believe I am right in saying that it was only adopted in view of special circumstances connected with the frequency of the alternating current available for the tests. With its main and auxiliary motor generators and motors and other gear, it reminds one too much of that mechanical absurdity the Heilmann locomotive, for it to be taken quite seriously as a solution of the railway traction problem. There is more to be said for the single-phase motor systems which have been developed by the Westinghouse, General Electric, and Union Companies, but even these have such very undesirable features that they cannot be said to be a solution of the problem. All single-phase commutator motors have the great disadvantage that the short-circuited coils under the brushes act temporarily as the secondary

Mr. Kilburn Scott.

of a transformer. During running this does not give trouble because the short-circuited coil is continually changing, and there is thus no time for the current to rise to a dangerous amount. Consider for a moment, however, the conditions when starting a train on an incline with the brakes down. If current is switched on before they are released, or if the train does not start immediately owing to the traction resistance being too great, then owing to the armature winding acting as the primary of a transformer, and the short-circuited coils under the brushes as secondary, the latter are almost certain to be burnt out. Various proposals have been made to meet this difficulty, one being the heroic idea of placing resistances between armature winding and the commutator segments, but clearly if the motor stands long enough, no resistance can save it. It is of course impossible to employ very large resistances because the dimensions of the motor would be unduly increased, and the efficiency diminished. Again, take the question of torque. This depends on the magnetic field, and in a series continuous-current motor with a certain load both field and torque are constant—that is to say, they do not pulsate. In a three-phase motor also the torque and field are constant, and in a two-phase motor nearly so. With a single-phase motor, however, the torque varies from zero to maximum, and back to zero with every complete alternation. To show what this means, let us suppose a certain freight train on a main line requires a maximum draw-bar pull of ten tons. Then with continuous or three-phase motors the locomotive may weigh, say, fifty tons, but if it has single-phase motors it must weigh eighty-five to one hundred tons. On the general question of cost there is no getting away from the fact that a three-phase generator costs some 25 per cent. more than a single-phase. (What should we think of a steam engineer who made a three-cylinder engine and then only ran it as a single-cylinder? yet this as a matter of fact is more or less analogous to the single-phase machine.) And what is true of the generator is also true of the motors, for when they are worked as single-phase the active material cannot be fully utilised. For a given power the machine must of necessity be larger and more expensive, and on to this the single-phase traction advocates want to add a commutator with all its additional trouble and expense. Why the commutator is the bugbear of the whole industry, and recent statistics show that more than half the breakdowns in electrical machinery are traceable to it.

Now as regards the extra wire required for three-phase, what does it really amount to? Is it not a fact that every single-track tramway line in this country has two wires, whereas with a bow trolley one would do? Yet no one objects to the two wires. Once admit the principle of bare wires, and a wire more or less does not matter; in fact there may in certain cases be a distinct advantage in having several wires. For example, if we assume that a certain system requires a certain amount of copper, then the more copper we put into bare wires overhead the less copper will be required in insulated feeders underground, and it is the insulation, excavation, laying, etc., of the latter which costs the money. The largest size of trolley wire which can be conveniently erected is 0·4 in. diameter, and three such wires required for three-phase will carry very

Mr. Kilburn Scott. much more energy than two such wires with single-phase. For a given voltage and given amount of energy the single-phase system must necessitate more money being expended on feeders underground.

Mr. Elliott Mr. J. M. ELLIOTT (*communicated*): The results of the experiments in high-speed electric railway travelling which the author has so fully placed before us will, I am sure, be much appreciated, for the information which we have gained in regard to (1) the behaviour of electric railway cars when travelling at very high speeds; (2) the method of transferring energy to them when moving rapidly, and (3) the electrical equipment of the car. But one of the problems which the Syndicate set itself, viz., "the proper construction of the permanent way," is hardly touched upon by the author. Railway engineers will, I feel sure, say that this very problem has by no means been satisfactorily dealt with. From the descriptions in the technical press it appears that the Marienfelde-Zossen line is practically a straight one, the sharpest curve being only 2,000 metres radius (1¼ miles approx.), and I understand the author to say that a curve of less radius is not advisable. If this is so, and I do not doubt it for one moment, it seems to me that the Syndicate has by no means arrived at the proper construction of the permanent way. In this country in particular and in other civilised countries it would be commercially impossible to lay out lines from town to town without introducing much sharper curves than the one referred to by the author, in order to avoid expensive earth works and valuable property. Under these circumstances experiments carried out on a straight piece of line such as that between Marienfelde and Zossen can lead to very little practical use in this country. It appears that in the final trials, guard rails were fixed inside the running rails on specially constructed chairs, and although we are told by the author that they were unnecessary, I think no one will deny that some such device would be an absolute necessity on curves such as are to be found on our British railways.

Then, again, the author mentions that the car with its motors, resistances, etc., was very carefully balanced in order to prevent side oscillations. This movement would be a continual source of danger at high speeds, and one dreads to think what the fate of such a car would be when running over a line where the rail has sunk a few inches on one side owing to the slipping away of the ballast in wet weather; such events are by no means uncommon even on our best-laid railways.

It may be suggested that with proper super-elevation of the outer rail, curves could be safely negotiated: but at a speed of 100 miles per hour the outer rail would require so great a super-elevation that it would be quite out of the question as regards the comfort of the passengers or the safety of the car if travelling at a much slower speed. I think that if further experiments are contemplated, the problem of traversing curves with perfect safety should not be shirked. A permanent way on the lines of the Behr monorail would seem to be a far more satisfactory solution of the difficulty, for here we have the centre of gravity of the car below the running rail, with guide rails placed in the most suitable positions on either side to counteract the centrifugal force of the car when travelling through curves, and guide

Mr. Elliott.

wheels with flanges to prevent derailment. In experiments which were made at Brussels in 1897 on a track with curves of 25 chains radius, a speed of over 80 miles per hour was maintained with perfect safety through these curves.

With regard to the collectors, I have been unable to find any information in the paper as to their height above the roof of the car; but from a description given in one of the technical journals, I gather that the height of the topmost collector must be some 12 feet above the roof of the car. If this be so, the use of such an arrangement would be practically impossible in this country with its numerous over-bridges, under which in many instances it is not possible to obtain a clearance of more than 1 ft. 6 in. to 2 ft. between the car roof and the over-bridge.

The Marienfelde-Zossen line appears to have been in the fortunate position of having no appreciable curves to deal with or over-bridges to pass under, but I think it will be admitted that these two important obstacles must be seriously considered and overcome before high-speed electric railroads can be made a commercial possibility. The benefits which would arise from a frequent and rapid train service between our large cities and towns are so great and the means of accomplishing this end is so essentially an electrical problem, that it is to be hoped that further efforts will be made not only in Germany but in this country also, toward a successful solution of high-speed travelling.

Mr. Siemens.

Mr. ALEXANDER SIEMENS (*in reply*): With regard to the observations which Professor Thompson made, I can only say that I adhered closely to the official reports of the Syndicate, and I have to make them responsible for the $0{\cdot}07\ V^2$. I may mention that I received the last report only on Tuesday morning, so that although I have just had time to put everything in it in shape for you here, I have not been able to go critically through it. As mentioned in the paper, the motors were not used in cascade in those experiments, and the acceleration indicator, I think, was simply a pendulum which for acceleration, flew out behind and, for retardation, in front. All the instruments were read so as to check each other. I have not given an exact description of the instruments because you will find it in the articles where the cars are described. Professor Thompson then asked why the locomotives on the Central London were found to be bad and the locomotives in this instance seemed to be recommended. I think that is only a misunderstanding; it was only an accidental form; they tried the 10,000-volt motors on locomotives because that was the handiest way of trying them. These experiments in no way prove either that the locomotives are better or that the motor-cars are better. With regard to Mr. Parsons' and Mr. Smith's remarks with reference to air-resistance, the shape of the car was studied and the Syndicate thought that a paraboloid would be the best; that is to say, a complete cone. Of course it could not be constructed exactly in that shape, but the roofs have been made in that form, and for the convenience of the driver the centre part of the paraboloid has been developed into a cylinder, but the best thing for air-resistance is a paraboloid. With all due deference I do not

Mr. Siemens.

believe that Mr. Patchell ran over the line. The line runs alongside the main line to Dresden, and he certainly has not gone over it. The line was made up last year into the same state as the first-class German main lines; I did not say that it was equal to the English first-class main lines. Mr. Patchell also wished to know the wind pressure behind the cars. I omitted to say that behind the car also a conical space of uniform pressure is formed equal to the pressure of air in the car, so that there is neither suction nor pressure if you make a hole at the back of the car; the apex of this space is about three metres behind the car. Mr. Mordey thinks that the people did the experiments as they ought not to have been done, and then he at once showed how not to discuss the paper, namely, by bringing in something totally different. Of course, the Oerlikon system is very interesting, and the Oerlikon collector is also very fine, but Mr. Mordey has absolutely overlooked that I say on page 895—"At first the conductors were carried by insulators, each fastened to a movable wooden arm, and the current was collected by a horizontal bar, turning round a horizontal pivot and pressed by a spring from above against the conductor. When the speed of running was increased, these horizontal bars jumped at the insulators and caused so much sparking that this arrangement had to be abandoned." And no doubt if the Oerlikon people run faster they will find the same thing. It was not that such a simple idea had not occurred to other people, and that they had not tried it, but it was found that it was impossible to run at high speeds with it. Then Mr. Mordey was also very indignant that the three-phase system has been tried there, as if it indicated that the three-phase system was the best. That was not so; the object of the experiment was twofold. First it was to see how you could, at very high speeds, transmit energy from a conductor along the line to the car, and by three years' experience the collector described in the paper has been developed. It was found that the simple horizontal bar, which Mr. Mordey has described so graphically, would not do it. The second thing was to find out what sort of permanent-way is wanted, and the Syndicate wished to settle the question whether an ordinary permanent-way was good enough for these high-speeds, and they have found that to be the case. Now that they have settled those two very important points, and know how to build the line upon which they can run fast trains, and have found a collector with which they can transfer electricity from the standing conductor on to the running car, they will devote their attention to the best way of utilising the electricity on the car. The locomotive which ran in 1902 demonstrated that the transformer need not be carried on the car, and that you still can utilise high-tension current. They do one thing after the other; they cannot do everything at once. The great losses at starting and stopping have been commented upon by the Syndicate themselves, but as this system is to be used for great distances, and as there should be only a fraction of the total time occupied by accelerating and stopping they are of no great consequence. I do not wish to discuss Mr. Mordey's very interesting system; he told us himself that it had been discussed two or three evenings at the Institution of Civil Engineers.

Mr. Siemens.

and it is, therefore, impossible for me to go into it in the five minutes which are now left. I thank the gentlemen who have taken part in the discussion very much for the kind way in which they have received the paper. If they desire any further information, it can be obtained from the official reports of the Syndicate, which are very complete, and of which the paper is really only a summary.

(*Communicated*): In reply to the observations communicated in writing I would refer Mr. Leach to the official reports of the Syndicate for the particulars of losses on open circuit, etc. They were omitted in the paper as they necessarily vary with local conditions, and have no appreciable influence on the results obtained.

The reference to single-phase motors in the paper was evidently misunderstood by Mr. Kilburn Scott, as the official reports express no opinion as to the relative merits of single-phase and polyphase motors.

In the paper it is stated that the permanent way of the experimental line is now equal to that of a German first-class main line, and Mr. Elliott will find that there is an official specification for that class of permanent way, some extracts of which have been given. His remarks about curves have been dealt with in the paper, but he should not overlook the fact that a monorail line would have to be specially built, just as much as a high-speed ordinary line, and the question of cost will decide between them. It is quite correct that collectors, as described, would be unsuitable for the lines in this country, but in experimenting it is always best to commence complicated trials under the easiest conditions, and the fact that the syndicate intends to continue the trials proves that their engineers do not consider that they have completely solved the problem of constructing high-speed electric railways.

The Chairman.

The CHAIRMAN: I am sure you will all join very heartily in according a vote of thanks to Mr. Siemens for his valuable communication.

The vote of thanks was carried by acclamation.

The CHAIRMAN announced that the scrutineers reported the following candidates to have been duly elected:—

Associate Members.

Hugh Maxwell Brown. | Francis Valentine T. Lee.

A THEORETICAL CONSIDERATION OF THE CURRENTS INDUCED IN CABLE SHEATHS, AND THE LOSSES OCCASIONED THEREBY.

By M. B. FIELD, Member.

(*Paper read at the Ordinary General Meeting, April 14, 1904.*)

SYNOPSIS:—Introductory Remarks—Magnetisation of iron pipe due to current within—Balanced current-system enclosed by pipe or trough—Balanced system can produce telephonic and other disturbances—Fundamental theorems—Effect of single alternating current in iron pipe discussed—Approximate mathematical investigation, Appendix I.—Variation of induction strengths at different depths below surface—Similarity with wave propagation—Wave length—Practical applications—E.M.F. induced in lead sheath of single-core cable—Induced current and sheath loss in two parallel single-phase cables—Effect of conductivity of soil—Determination of magnetic field surrounding cable systems; two parallel cables; three-phase cable—Variation of magnetic field surrounding cable during cycle—Figs. 11, 12 representing variations in case of three- and two-phase cables—Formulæ for determination of same, Appendix II.—Longitudinal E.M.F. induced at different points around circumference of three-core cable—Approximate numerical calculations of sheath loss; two parallel single-phase cables; three-phase cable—Loss in earth shield—Proposed method for reducing same.

Introductory Remarks.—It is now generally recognised by engineers that single-core cables designed for carrying alternating currents of any magnitude cannot be laid in separate iron pipes, owing to the strong alternating magnetic field which will be created in the mass of the pipe by the current, and the hysteresis and eddy-current losses consequent thereon. On the other hand it is considered quite permissible to lay concentric or three-core cables (for three-phase currents) in iron pipes or troughs, for wherever there is included in the same cable both the "go" and the "return" conductors so that at every instant the algebraic sum of the currents within the pipe or trough flowing in either direction is zero, there cannot be any closed magnetic lines entirely surrounding that cable created by the currents within it—a statement often otherwise expressed by the words that the line-integral of the magnetic force taken round any closed path whatever entirely surrounding the cable is zero.

As an example we may mention a case that came under our notice some little time since, where three cables of ample cross section carrying alternating three-phase current of from 600 to 1,000 amperes per phase, the frequency of which was 25, were laid through short lengths of wrought-iron pipe whose diameter was 3¼ inches inside and 3¾ inches outside. The temperature of the pipes soon rose to such a degree as to endanger the insulation of the cables, and it was quite

evident that the seat of the generation of the heat was in the iron and not in the cable. These cables were subsequently withdrawn, and a three-core cable drawn into each pipe. The corresponding cores were connected in parallel at each end, with the result that the iron pipes remained quite cool under full-load conditions.

Similarly, although two single-core cables for a single-phase system cannot be laid in separate pipes for the reasons explained, they may be laid in the same pipe or trough without fear of engendering very serious hysteresis or eddy-current losses in the iron.

This, however, does not in the least imply that there is no external magnetic field produced by a three-phase current in a three-core cable; indeed a very considerable field may exist giving rise to telephonic disturbances in neighbouring circuits, eddy currents in the lead sheath or iron pipe itself, and even earth currents. Similarly if the "inner" of a so-called concentric cable be not truly concentric with the "outer," an external field will result, while if several concentric or three-core cables be connected in parallel at both ends, and for any reason the resistance of one conductor be unduly increased (*e.g.*, through a bad connection) so that the algebraic sum of the currents included in this cable is not zero, not only will an external field exist, but there will be magnetic lines entirely surrounding the cable in question giving rise to losses if laid in an iron pipe.

In this connection we may call attention to a clause in Messrs. Constable and Fawssett's recent paper read before the Institution of Electrical Engineers, where, in speaking of concentric cables, they say (vol. 32, p. 721):—

"The fact that an external field exists round these cables is proved by the humming noise produced in the telephones connected to pilot wires laid parallel and close to the cables; that this noise is not due to leakage entirely is shown by the fact that it is slight during times of no load, and very loud at times of heavy load."

In this communication we shall consider the external fields produced near single, concentric, three-core cables and the like, and investigate the losses occasioned thereby. We shall first consider the conductors to be of circular cross section, and the currents in the same to be distributed either uniformly over the section or at least as a function of the radius from the centre of the section only (a distribution which we here describe for brevity as "cylindrical").

At first sight it may seem that this is an unwarrantable assumption in the case of cables containing an unsymmetrical arrangement of conductors. In such instances the mutual induction between the different cores will tend to disturb the otherwise uniform or cylindrical distribution of the current in each core. It must, however, be remembered that each core is built up of a number of strands laid together with an axial twist, so that all the strands forming any one layer successively pass through exactly similar positions with regard to the other cores. This, then, helps largely to maintain the uniform or cylindrical current distribution; indeed, when we think that in order for any other distribution to occur current must continually pass from strand to strand, and remember the small area of contact and small differences of potential

between contiguous strands, any apology for our assumption seems unnecessary.

At the end of Appendix II. we indicate how the losses in cable sheaths enclosing cores of cross-sections other than circular may be dealt with. There is no intrinsic difficulty in such calculations, but the method is undoubtedly somewhat laborious.

Fundamental Theorems.—The following theorems which we here merely enunciate, and which will be found discussed at length in text-books dealing with the subject, form the basis of this paper :—

(1) The magnetic force at any external point due to a current flowing longitudinally in an infinite straight cylindrical conductor (or hollow cylinder) is the same as if the whole current were concentrated at the axis. The magnetic force is expressed by $2\ C/r$, where C is the current in C.G.S. units, and r is the distance in cms. of the point in question from the axis.

(2) The line integral of magnetic force taken round any closed path surrounding a conductor carrying a current C is $4\ \pi C$.

(3) The total number of lines which have cut across or enclose any element of length (reckoned parallel to the conductors) due to any system of straight parallel conductors, is equal to the algebraic sum of the lines due to each conductor taken separately, which would surround the element in question, if it existed independently of the other conductors.

(4) No field exists in the interior of a hollow cylindrical conductor due to a longitudinally flowing current.

Single-core Cable laid in Iron Pipe.—If we consider a long straight single-core cable carrying an alternating current we know that the magnetic field naturally spreads out into space in the form of concentric circles, unless it penetrates a portion of space of varying magnetic permeability, in which case the magnetic lines will tend to concentrate along the path of lowest magnetic reluctance, giving rise to a general distortion of the magnetic field distribution from that of concentric circles.

Take the case of a cable laid in, and lying at the bottom of, an iron pipe ; the greatest proportion of the magnetic field produced will follow circularly round inside the iron of the pipe as shown by the dotted line, since this is the path of lowest magnetic reluctance, but there will also be some magnetic lines both inside and outside the pipe. Now if c be the current in amperes in the cable, $\frac{4\ \pi\ c}{10}$, is the line integral of the magnetic force taken round the dotted line, and this multiplied by the permeability and divided by the length of path in cms. gives the induction in C.G.S. measure inside the material. As an example, suppose the cable to be carrying a current of 1,000 amperes, and the pipe to have a mean diameter of $3\frac{1}{2}$ in. and a thickness of $\frac{1}{4}$ in., the mean length of the magnetic path inside the iron will be 28 cms. This magnetising

force will be sufficient to bring the iron to a very high degree of saturation; if wrought iron, the induction will be in the neighbourhood of 16,000 lines, or if cast iron, 7,000 lines per square cm., while a current of only 140 amperes would be sufficient to produce an induction of 10,000 lines per square cm. in the former.

If now we assume that the current in the cable is alternating, having an effective value of 100 amperes, the magnetisation inside the pipe will likewise alternate with the same frequency. In this case, however, as we shall see later on, there will be induced in the pipe currents flowing longitudinally along the inner surface and back along the exterior surface. These currents will have the effect of choking back the magnetisation in the interior of the pipe-wall, and may even reduce it to zero in the middle, but will leave it unaffected at the interior and exterior surfaces. If, however, the pipe be so thin that its electric conductance is very low, the induced currents will not have a very great choking effect, and the induction will then reach the full value above indicated, and be practically constant over the cross section of the pipe. The hysteresis loss with a maximum induction of 10,000 lines per square cm. at a frequency of 50 ∿ per second in wrought iron is of the order of 1 k.w. per cubic foot. If the pipe be thicker so that the induction is not sensibly constant over the cross section, the hysteresis loss will be less, but to this we must add the eddy-current loss, which will then assume serious proportions.

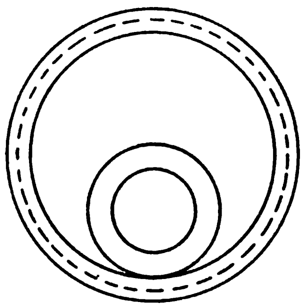


FIG. 1.

In Appendix I. we have investigated mathematically the case of a single-core cable carrying an alternating current, laid in an iron pipe. Although, as we have already stated, it is perfectly well known that such practice is inadmissible, nevertheless the thorough appreciation of the underlying magnetic and electric phenomena is of such far-reaching importance generally, that we have not deemed it ill-advised to include a brief investigation of the subject in this paper.

We have not thought it necessary to give all the intermediate steps in Appendix I., but would refer those interested, to the article of Professor J. J. Thomson on the Eddy Currents in Iron Plates, published in the issue of the *Electrician* of April 8, 1892, and to the subsequent issue containing some most important deductions by Professor Ewing based upon Professor Thomson's equations. We have compared our equations with those above cited, and though in somewhat different shape, they are in substantial agreement therewith. It is to be noted that the theory given in the Appendix only holds good for pipes where the diameter is large in comparison with the thickness, for it assumes that the length of the path of all magnetic lines within the iron is equal to the mean circumference of the pipe. The assumption is similarly made that the total longitudinally flowing current in any hollow cylinder, bounded by two cylindrical surfaces co-axial with the centre

line of the pipe, whose difference of radius is δx, is $LA_x\delta x$, where $L = \pi(d + h)$, A_x being the current density in the hollow cylinder in question, and d the internal diameter of the pipe (Fig. 2).

Secondly, we have assumed the magnetisation at every point in the iron to be directly in phase with the current producing it, or more strictly with the magnetic force existing at the point in question, and the permeability to be constant throughout.

It will be thus seen that the case is by no means a general one—a completely general mathematical solution we consider would be well nigh impossible, but much valuable information may be gained by considering certain special cases which approximate to the truth.

As a matter of fact, we apply later on the results given in the Appendix to the case of an iron pipe whose inside diameter is 3½ in. and wall thickness ¼ in. In this case the maximum divergence of the length of the magnetic path from the mean is 7 per cent., hence we must consider the numerical results obtained as only indicating the order of magnitude of the phenomenon. This after all, however, is sufficient for the purpose of this paper.

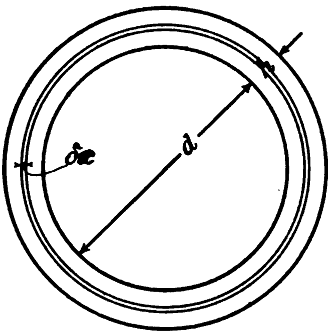


FIG. 2.

Two cases are considered in Appendix I.: first, when the pipe is laid in dry concrete so that all induced currents are confined to the pipe itself; second, when the pipe is well earthed so that the ends may be assumed to be at the same potential. In this case the earth affords a return for the currents in the pipe.

Examining the equations deduced, we see that in Case 1 the induction is a maximum at the interior and exterior surfaces of the pipe, being due at these places solely to the current in the cable. This is obvious, for since no currents leak out into the earth there must be the equivalent of two concentric current-sheets, currents flowing longitudinally in one direction along the interior portion and in the opposite direction along the exterior portion of the pipe. The sum total of the current in each sheet must moreover be the same, in other words the surface integral of current density over the section of the pipe must be zero: hence there can be no magnetic effect due to these currents at the interior and exterior surfaces. They do, however, produce a magnetic effect at the middle of the pipe wall, and this will be a demagnetising effect, so that if the pipe be moderately thick the induction at the middle of the thickness may be reduced to practically zero value.

Fig. 6 shows the case for a wrought-iron pipe as above, enclosing an alternating current of 500 amperes at 25 ∿ frequency worked out from the formulæ given in Appendix I.

The maximum induction reached at different radii, as also the maximum values of the density of the longitudinally flowing currents,

are shown independent of their phase relation. The equations show that the phase of both induction and current density is continuously altering as one travels towards the middle of the pipe wall. The current at the inner face is exactly out of phase with the current at the outer face, but the phase of the induction is symmetrical on both sides of the middle of the pipe wall. If the pipe be sufficiently thick,* the total current of each current-sheet is equal to the current in the cable, provided the magnetisation in the outer and inner skins be not driven too near the saturation point on the magnetisation curve.

Professors Thomson and Ewing, in the articles above mentioned, show that the eddy currents and magnetisation in iron plates under alternating magnetic forces do not penetrate beyond a certain distance below the surface. See also Fig. 3. The formulæ allow us to calculate

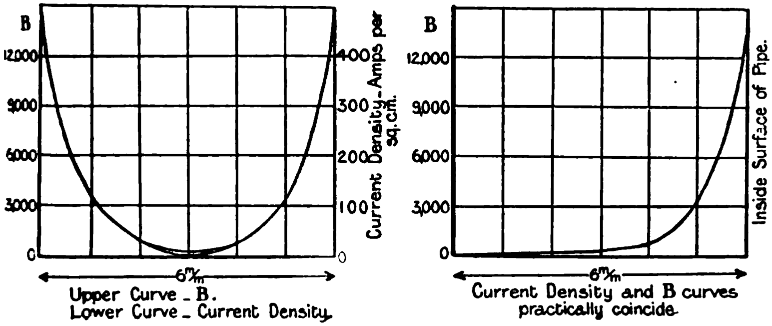


FIG. 3.

roughly the total hysteresis and eddy-current losses in the case in question; they are—

Eddy-current loss per cubic foot 4·15 k.w. } For an effective current in
Hysteresis loss per cubic foot 0·125 k.w. } the cable of 500 amperes.

One cubic foot corresponds, in the case we have taken, with 55·5 feet length of pipe.

Appendix I. shows us that the magnetic effect within the pipe wall is equivalent to two waves entering into it simultaneously from the interior and exterior, the amplitude of the wave decreasing according to a logarithmic law in the direction of propagation.

The wave length is $\lambda = 2\pi/m$. In the case under consideration † $\frac{1}{m} = \frac{1}{14}$ cms., hence $\lambda = 4{\cdot}5$ mm. and the velocity of propagation radially will be 11·25 cms. per second.

For very high frequencies we should expect to find magnetism only at the inner and outer faces of the pipe.

* In considering thicker pipes we must, of course, assume their diameters are correspondingly increased, or the theory becomes quite inapplicable.

† $\mu = 2{,}000$, $\sim = 25$.

Summing up our deductions in Case 1, we may say that in thin pipes we have the magnetic induction which we should expect due to the current in the cable, but in thicker pipes this value of the induction is only found at the interior and exterior surfaces. While, therefore, for thicker pipes the hysteresis loss somewhat decreases, we have to add to this the eddy-current loss, which then assumes a serious magnitude. Any one who is interested can draw his own deductions from the formulæ given for Case 2, but enough has now been said to show the importance of avoiding the drawing of even short lengths of cable through iron pipes (perhaps more on account of the danger to the insulation of the cable than of the amount of the losses). It might be thought from the above considerations that the use of cast-iron cable clamps, as, for example, illustrated in Fig. 4, should be avoided, but we did not find any heating in some we used on one occasion for clamping cables carrying 300 amperes at 25 $\sim$. On the other hand manufacturers of large switches, transformers, etc., are aware of the fact that abnormal heating due to hysteresis is likely to occur where heavy connections carrying large currents are brought through cast- or wrought-iron fittings, oil tanks, etc., and that suitable precautions must be taken to avoid trouble from this cause.

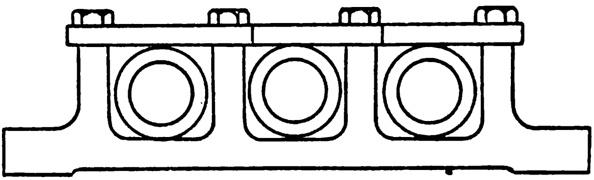


FIG. 4.

Currents induced in Sheaths of Single-core Cables.—Hysteresis losses do not, of course, occur in the lead sheaths of cables, and we will now turn our attention to the eddy-current loss which does take place.

If we consider the lead sheath as a number of longitudinal strips or wires arranged contiguously, we see that as the magnetic field spreads out into space in expanding circles, each magnetic line of force cuts normally across each strip, generating therein a longitudinal E.M.F. If the cable be laid direct in the earth (so that no appreciable distortion of the magnetic field takes place), it is obvious that the longitudinal E.M.F. at all points around any circumference will have the same value and phase relation.

In order to get an exact idea of what takes place, let us consider the cable as laid on the solid system, the sheath being insulated in a bitumen trough; then we see that an alternating difference of potential will exist between the ends of the lead sheath, but practically no currents will flow along the sheath, as there will be no closed circuit. If now both ends of the sheath were effectually grounded, a return circuit would be afforded by the earth and alternating earth-currents would flow between the ends, spreading out to a great distance sideways in all directions. As a matter of fact, this case cannot actually occur in

practice, because there must of necessity be a return conductor somewhere, and the earth currents to which this would give rise, would, to a large extent, neutralise those of the first conductor. If we consider a single conductor by itself as carrying current, we get landed in considerable difficulties, because we find mathematically that the sum total of the magnetic field throughout space is infinity, giving rise to an infinite longitudinal E.M.F. in the lead sheath, and requiring an infinite potential difference between the ends of the cable before any appreciable current could be caused to flow.

The reason of this seeming paradox is as follows: if we do not consider the effect of the return conductor, we are really assuming that it is lying at an infinite distance, *i.e.* we are considering a circuit of infinite area; but we know that if such a circuit were possible, its coefficient of self-induction would be infinite; in other words, the total magnetic flux interlinked with the circuit due to any finite current would be infinitely great.

Two Parallel Single-core Cables.—We will therefore consider a more practical case, viz. a circuit made up of two long lead-sheathed cables lying parallel to one another. Let us picture them again as laid in bitumen troughs, and suppose the two sheaths connected together at either end. Clearly the E.M.F.'s induced in the two lead sheaths will be in opposite directions, so that now we have a closed circuit in which the sheath currents can circulate.

It will be observed that we have practically an air-core transformer, both primary and secondary having but one turn. If now we can

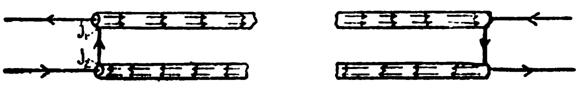


FIG. 5.

calculate the induced E.M.F. per unit length in the sheath, it will be a simple matter to determine the total loss in this secondary circuit.

If v = E.M.F. per cm. length of sheath (in volts),
ρ_s = specific resistance of sheath (in ohms),
a = cross-sectional area of sheath (in sq. cms.),
l_1 = length of both cables together (in cms.),

the total loss will be $\frac{v^2}{\rho_s} a\, l_1$ watts.

Effect of Conductivity of Soil.—If the cables be laid direct in more or less conducting soil it would seem at first sight as if the currents would leak across from sheath to sheath through the soil and thus render the problem indeterminate. This, however, is not the case, for if any two points on the sheath be at zero potential, and the same E.M.F. per unit length be induced at all places between these points, the current will adjust itself so that the drop per unit length equals the induced E.M.F. per unit length, and there will be no variation of potential along the sheath. This is the case we have above: we know the points that

j_1 and j_2, Fig. 5, are at zero potential, therefore the whole sheath will likewise be, and no currents will leak out into the earth. A proof of this theorem, if proof be needed, is as follows:—

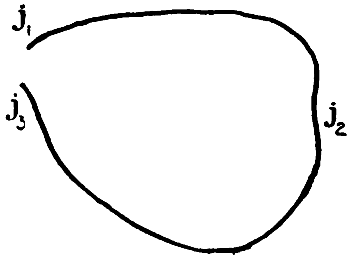


FIG. 6.

Let $j_1\, j_2\, j_3$, Fig. 6, be any uniform conductor, immersed in any medium of variable conductivity, and let the points j_1 and j_3 be at the same potential. In each unit of length is induced the E.M.F. v; c is the current at any point of the conductor; then considering any element δl, the rise of potential along it will be

$$\delta v_1 = v\,\delta l - c\,\omega\,\delta l,$$

ω being the resistance of unit length.

Integrating from end to end of the conductor, we have—

$$vl_1 = \omega \int c\,dl,$$

where l_1 is the total length of the conductor.

Now the power generated in the conductor is $\int vc\,dl = v^2 l_1/\omega$, but the power expended in the conductor is $\omega \int c^2 dl$.

Now $c = \frac{1}{\omega}\left(v - \frac{dv_1}{dl}\right)$, hence power expended is

$$\frac{1}{\omega}\int\left(v - \frac{dv_1}{dl}\right)^2 dl = \frac{v^2 l_1}{\omega} + \frac{1}{\omega}\int\left(\frac{dv_1}{dl}\right)^2 dl - \frac{2\,v}{\omega}\int dv_1.$$

Now the last term is zero, and unless dv_1/dl be zero at every point along the conductor, the second term has a positive value. But a positive value would imply that the ohmic loss was greater than the total power generated in the conductor. It follows, therefore, that $(dv_1/dl) = 0$ at every point, *i.e.* there is no variation of potential along the conductor and therefore no currents can leak out into the surrounding mass.

We must, however, not lose sight of the fact that longitudinal E.M.F.'s will be induced in all paths through the earth parallel with the cable, along which will flow earth-currents, whose magnitude will depend on the conductivity of the soil, and that these earth-currents will exert a choking back tendency preventing the free propagation of the magnetic field into the medium. For instance, if the cables were laid in a surrounding medium of perfect electrical conductivity, no magnetic field could penetrate into it, and therefore no E.M.F.'s would be induced at the exterior surfaces of the cable sheaths.

In the case of dry earth, on the other hand, the conductivity is extremely poor and the induced E.M.F.'s at any distance from the cable small. Then, again, these earth currents, owing to the high resistance of their paths, will be in quadrature with the currents in the cable cores producing them, and their effective reaction will be very small. We shall, therefore, in this investigation neglect the choking effects of these earth currents, and may say that our results will represent the higher limit—that is, the actual losses will if anything be somewhat less than those calculated. While for dry earth the error caused by this assumption will probably be negligible, the results obtained would quite possibly be wholly incorrect for such a case as a cable circuit laid in deep sea water.

We have then a very simple rule for calculating the sheath loss provided we know the induced E.M.F. per unit length, and the sheaths

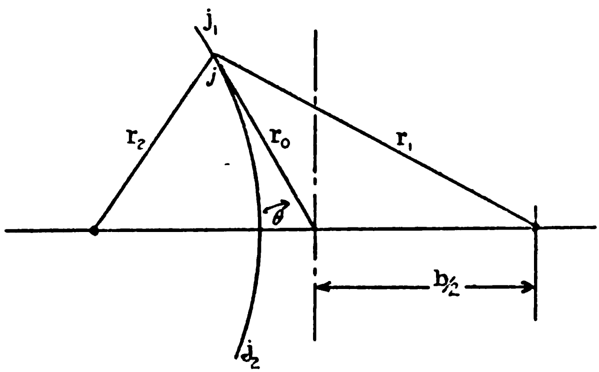


FIG. 7.

are connected or well grounded at either end; in this case our rule is independent of the conductivity of the soil. It is, the loss equals V^2/R, where V is total E.M.F. induced in the whole lead-sheath circuit, and R is the resistance of the same.

Magnetic Field surrounding Cable.—In dealing with the sheath-losses in single and multiple core cables we must form a mental picture at least of the approximate distribution of the external magnetic field produced at different periods of the cycle. There is no difficulty in constructing the external and internal lines of force, provided the surrounding medium be not magnetisable, and we propose to consider briefly how this may be done.

In Fig. 7 we represent the two conductors of a circuit, current flowing up one and down the other. $j_1 j_2$ is any line of force passing through the point j. We know that the total number of lines of force that have cut across or surround unit length of an imaginary line (parallel with the current-carrying conductors, and passing through j) is given by the expression—

$$\frac{2C}{10} \log_\epsilon \frac{r_1}{r_2}.$$

In other words, if we picture two planes normal to the conductors and unit distance apart, and consider a very thin wire passing normally between the planes, *i.e.*, lying parallel with the conductors, a certain definite number of lines of force will surround the unit length of the wire comprised between the two planes. If the wire pass through j the number of lines will be given by the above expression.

Now let the imaginary wire travel along the line of force j_1 j_2, its length being always parallel to the conductors as before, clearly it will cut no magnetic lines in its motion, and therefore the number of lines which surround each unit length of the wire remains unaltered no matter what position it may take, provided always it does not leave the line of force j_1 j_2, hence the condition—

$$\frac{2C}{10} \log_\epsilon \frac{r_1}{r_2} = k, \text{ or merely } \frac{r_1}{r_2} = \text{constant},$$

holds for the complete family of lines of force of this system.

The letter k here represents the number of lines surrounding unit length of an imaginary line drawn parallel to the conductors through a point in the field of force. In the diagrammatic representation of the magnetic field this unit length of course becomes a point, and we may, for simplicity, adopt the convention of speaking of the number of lines which surround a given point in the diagram or field of force, provided we do not lose sight of the fact that the point in question represents merely the end view of a line of unit length passing through it, normal to the plane of the diagram.

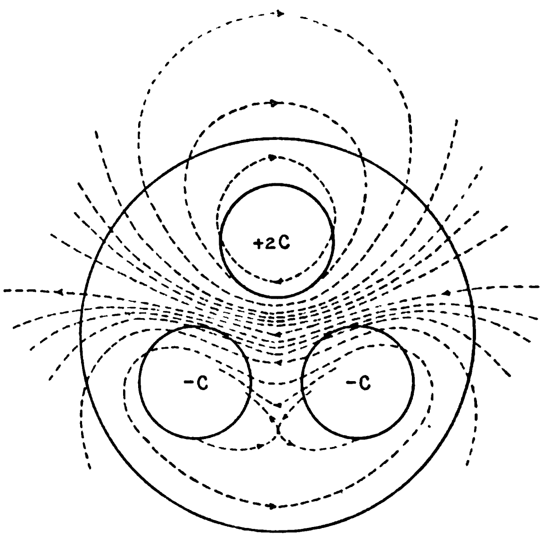


FIG 8.

We can readily express the above condition in polar co-ordinates if we remember that—

$$r_1^2 = \frac{b^2}{4} + r_0^2 + br_0 \cos \theta.$$

$$r_2^2 = \frac{b^2}{4} + r_0^2 - br_0 \cos \theta.$$

But in Appendix II. we point out that these lines of force consist of a series of eccentric circles, and we give the rule for finding the centre of any given line of force.

In the various cases subsequently treated, we find the simplest way of constructing the field is to calculate the value of k for a number of points along a number of radii. We can then plot k and r for each radius, and by interpolation draw a family of lines of force, each line passing through the same value of k in each radius.

If we further mark against each line of force its respective k-value, we obtain a chart showing not only the general distribution of the field of force, but also the total number of lines of force surrounding any given point in that field; and furthermore we may obtain the strength of the magnetic induction at any point of the field, by taking the difference of the k-values of two lines, one on either side of the point, and dividing by the distance between them measured normally.

Such charts have been carefully drawn out by the aid of the formulæ given in Appendix II. for certain specific cases :—

Fig. 8 represents a three-core cable, the current in one conductor being $+ 2c$, and in each of the other cores $-c$.

Fig. 9 represents the configuration in the case of a two-phase cable, with two insulated cores and a common outer, when the current in each of the insulated cores is $+c$, and in the outer $-2c$.

Fig. 10 represents the same cable, the current in one of the insulated cores being zero, in the other $+c$, while $-c$ flows in the outer.

Figs. 11 and 12 represent the successive configurations that occur during one half-cycle in the above two instances; in the case of the three-core cable the time-intervals represented in the diagram are $\frac{1}{12}$th cycle, and in the two-phase case $\frac{1}{8}$th cycle. In the former case we see that an irregularly rotating two-pole field is created, but in the latter a more complicated state of affairs exists, the field constantly fluctuating between a four-pole and a two-pole distribution.

The foregoing configurations really assume that the various current-carrying conductors are straight; that is to say, no account has been taken of the fact that, in reality, they are spiralled round the cable axis. Since, however, it is the magnetic field immediately in the neighbourhood of the sheath that concerns us most, the configurations obtained on the above-mentioned assumption may be taken as quite accurate, for it is only at relatively large distances from the cable axis that the effect of the spiralling is manifest, in distorting the configuration.

It will be observed that in all the above cases the integral of current density over the whole cross section of the lead must be zero. This must manifestly be so, for if not, there would be on the whole a current flowing longitudinally in the sheath. This current would produce magnetic lines surrounding the cable, but since the core currents inside can produce no such field and the sheath entirely surrounds these cores,

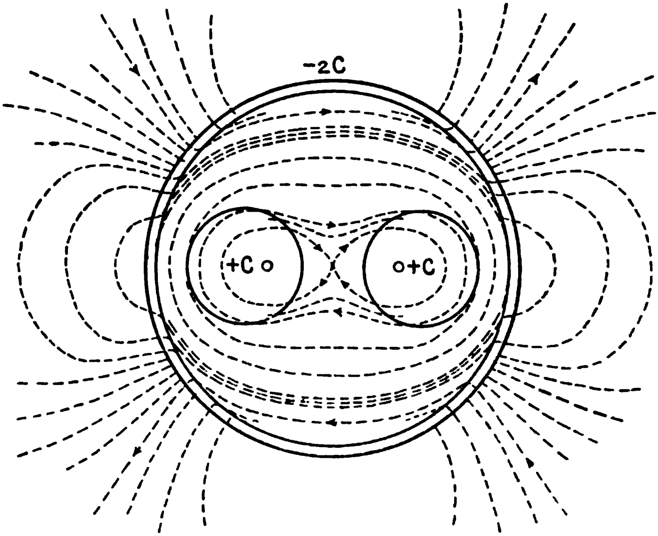


Fig. 9.

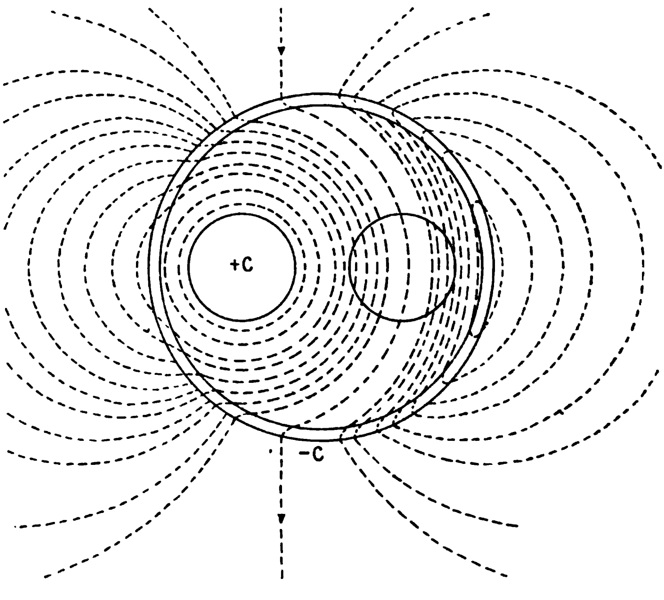


Fig. 10.

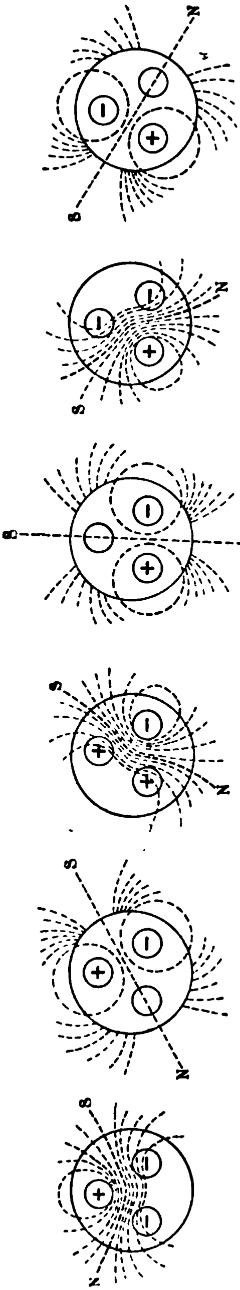


FIG. 11.—Successive Distributions of Magnetic Field around Three-Phase Cable during one-half cycle. Time-intervals of $\frac{1}{12}$th cycle.

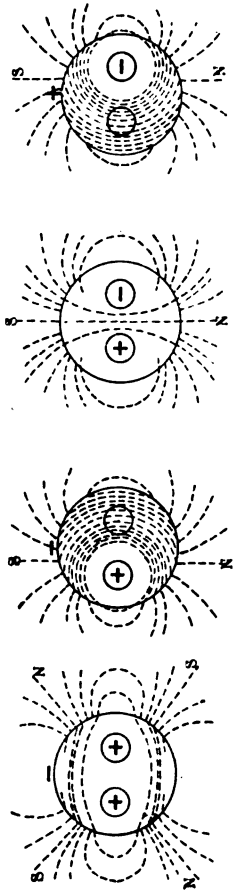


FIG. 12.—Successive Distributions of Magnetic Field around Two-Phase Cable during one-half cycle. Time-intervals of $\frac{1}{8}$th cycle.

it is not possible for the induced sheath currents to produce such a distribution.

It can also be readily demonstrated that under these circumstances there will be no progressive variation of potential along the sheath, so that we may apply our previous rule that the loss in any longitudinal strip is V^2/R, where V is effective E.M.F. induced, and R the resistance of the same.

Variation of Induced E.M.F. in Three-Core Cable Sheath.—The E.M.F. generated per unit length parallel to the cable will be $10^{-8}\frac{dk}{dt}$ volts.

If c_1, c_2, c_3 are the currents in the cable cores, and r_1, r_2, r_3 the distances of the point P of the sheath from the core axes respectively, the longitudinal E.M.F. per unit length at P is—

$$\frac{1}{5}\left(\frac{dc_1}{dt}\log\frac{r_1}{r_3}+\frac{dc_2}{dt}\log\frac{r_2}{r_3}\right)$$

provided $c_1 + c_2 + c_3 = 0$, *i.e.*, provided the system be a balanced one.

If c_1 and c_2 are sine-functions, of amplitude $\bar{c}$, and differing in phase by the angle $\frac{2\pi}{3}$, the amplitude of the E.M.F. is—

$$\frac{2\pi\sim\bar{c}}{5}10^{-8}\sqrt{\left(\log_\epsilon\frac{r_1}{r_3}\right)^2+\left(\log_\epsilon\frac{r_2}{r_3}\right)^2-\log_\epsilon\frac{r_1}{r_3}\log_\epsilon\frac{r_2}{r_3}}.$$

We can make this calculation for all points round the sheath of the cable in any particular instance, and construct a curve showing the E.M.F. per unit length longitudinally and the position around the sheath. Calling this E.M.F. v, as before we take the mean square value, divide by the specific resistance and multiply by the area of exposed cross section of the sheath to obtain the total loss per unit

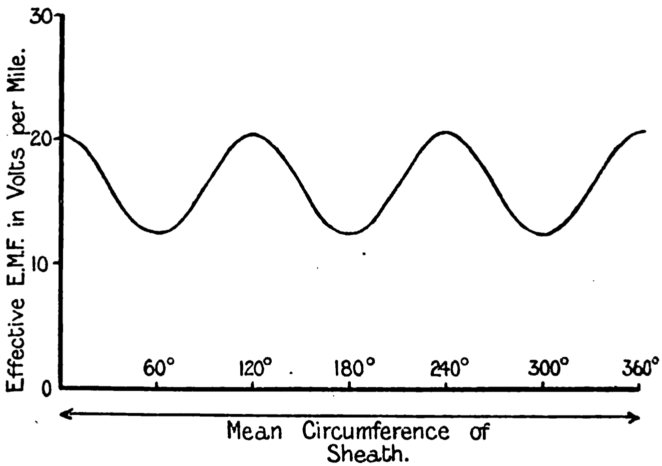


FIG. 13.

length. Fig. 13 shows the variation of v at different points around the circumference of the three-core cable the dimensions of which are given below. It is to be remarked that Fig. 13 in no way represents the relative phases of the induced E.M.F. at different points of the circumference, but merely the effective value.

It is perhaps hardly necessary to point out that in making the calculation of the loss per mile of cable, we have to take our length a little greater than the total length of the cable and cross-sectional area proportionately less, as we must consider our imaginary strips which form the sheath spiralling round the axis with exactly the same lay as the cable cores, so that each strip may be considered at every point along the cable the same distance from any one conductor.

Approximate Calculation of Sheath Losses.—We now pass on to the approximate calculation of the sheath losses in a few definite cases, which are taken principally by way of example :—

Let us consider two lead-sheathed cables whose centres are separated by distance b, the mean radius of sheath in each case being a, Fig. 14.

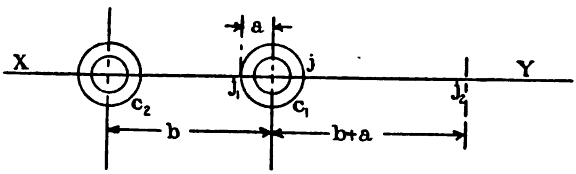


FIG. 14.

At the moment current is going down the core on the right and coming up that on the left, let us consider the number of lines of force that enclose the point j. If we travel along axis XY from j to an infinite distance, the total number of lines due to the current C_2 will be the same as the number due to C_1, traversed in passing from the point j_2 to infinity, but of opposite sign, hence the total effective number of lines which surround the point j is equal to those due to C_1 which cut across the axis between the points j and j_2. Had we chosen the point j_1 instead of j the number would have been slightly less, but if b is great compared with a the difference will be inappreciable. The actual effect that this will have in our case will be that the E.M.F.'s on the inside the cables will be rather less than those along the outside, giving rise to a variable current density at different points of the sheath.

In any case, if r is the distance of the point in question from the centre of the other cable the total number of lines cut by it per unit length will be $0{\cdot}46\ c \log_{10} \frac{r}{a}$, c being the current in amperes flowing in each core.

Taking an actual case, let $b = 12''$, $a = 0{\cdot}587''$, $\sim = 60$, effective current $= 200$ amperes, then the mean effective E.M.F. in the sheath in volts per mile will be—

$$2\pi \times 60 \times 200 \times 0{\cdot}46 \log_{10} \frac{12}{0{\cdot}587} \times 10^{-8} \times 2{\cdot}54 \times 12 \times 5280 = 73 \text{ volts}$$

approximately.

Taking the cross section of the sheath as equal to 0·46□″ and the specific resistance of lead as 21 microhms, the sheath current will be 64·5 amperes, representing a loss of 4·7 k.w. per mile length of cable.

We may here conveniently call attention to the external field of an imperfect so-called concentric cable, as already referred to in the earlier portion of this paper. Let us suppose that due to faulty manufacture a certain amount of eccentricity exists. The field of force will be that represented in Fig. 10. External to the outer conductor, the field will be that due to two currents concentrated at the centres of the inner and outer conductors respectively, while inside the outer conductor the field will be that due to the inner conductor only.

It is easy to show that a cable carrying 200 amperes, having an eccentricity of $\frac{1}{8}$ in., would produce an E.M.F. in a parallel pilot wire situated 4 in. away of 3 to 4 volts per mile. A telephone connected to a few miles of such a pilot wire would give a very loud humming, and it is clear that if the cable and pilot wire were laid in the same iron trough, a very much smaller eccentricity would produce a loud humming in the telephone connected to the pilot wire. We think, however, this can hardly account for the phenomenon observed by Messrs. Constable and Fawssett, for even supposing an eccentricity to exist throughout the whole length of the cable, it is hardly possible that there would be no twist in the cable, which, of course, would tend to neutralise the effect.

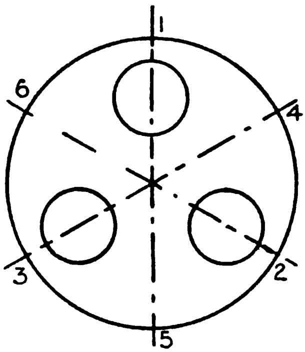


FIG. 15.

If, on the other hand, two or more concentric cables were connected in parallel at both ends, and the resistance of one outer, say, were increased unduly due to a faulty connection at some junction-box, the correct distribution of current between the various cores would be disturbed, under which circumstances telephonic phenomena would be readily accounted for.

In the case of the three-core three-phase cable we can calculate the E.M.F. at the six points on the sheath, 1, 2, 3, 4, 5, 6, Fig. 15, as if we had merely two conductors, each of these points being situated at the same distance from two cores. The maximum E.M.F. at 1, 2, 3 will be the same, likewise at 4, 5, 6; hence if we calculate it as previously explained for two points diametrically opposite, say 1 and 5, and take the root mean square of these values, this will be good enough for a rough estimate of the sheath loss. For example, we find the E.M.F. at 1 is 20·3 volts per mile, and at 5, 12·6 volts per mile in the case of a three-core cable having the following dimensions:—

Circular cores of radius...	0·275 in.
Distance between centres of cores	0·8 „

Distance between centre of cable and centre of core	0·463 in.
Mean radius of sheath	1·05 ,,
Thickness of sheath	0·188 ,,
Current per core (effective)	200 amperes
Frequency	60 ,,

Since the loss is proportional to the square of the E.M.F., we have to take the $\sqrt{\text{mean sq.}}$ of the above values rather than their true mean—
$\sqrt{\dfrac{20{\cdot}3^2 + 12{\cdot}6^2}{2}} = 16{\cdot}9$, hence the total sheath loss per mile will be 0·67 k.w. per mile.

The Board of Trade are nowadays advocating a copper earthed sheath directly under the lead, which will manifestly considerably add to this loss.

Suppose we take the worst case of a copper sheath directly beneath the lead, made up of strips of copper 1/32 in. thick, wound with the same lay as the cores, then the resistance of this earth sheath will be approximately one-half of that of the lead, so that the total sheath loss is brought up to 2 k.w. per mile, which is by no means a negligible quantity.

If we further assume that our three-core cable is laid in an iron trough or is steel armoured, we know that the total external field will be largely increased, to what extent is difficult to say: the problem of calculating the field of force due to an unsymmetrical arrangement of conductors in an iron trough is an extremely complex one. We have no experiments to guide us, and it is dangerous to hazard a guess, although we feel that to say that the total field may be doubled, is not at all outrageous. The losses depend on the square of the field, so that doubling the field strength at every point would mean four times the loss, or 8 k.w. per mile. These possible causes of loss cannot therefore afford to be overlooked by engineers.*

If the copper strips forming the earth shield be not wound on with the same lay as the cores, there will be a relative crossing between the cores and strips. Thus if, at any one instant, we follow along an individual strip, we find the induced E.M.F. in it periodically reversing, and the total E.M.F. induced in that length of strip which forms one complete spiral round *any one particular core*, will be zero. It follows, therefore, that the currents flowing longitudinally in the strips must at intervals pass from the lead sheath into the copper strips, and *vice versa*, in order to form closed paths. Any two strips may be considered as forming together a loop through which magnetic induction threads, but if the lay of the cores differs from that of the strips, the loop may be considered to be twisted in the magnetic field. If eddy

* It appears to be generally considered advisable to provide a copper earth shield where the armouring is applied in the form of steel tapes, partly on account of the difficulty in making suitable electrical connections in the armour at a cable joint. Where the armouring takes the form of steel wires outside the cable, or where the cable is drawn into iron pipes which are carefully bonded together where they make joint, additional earth shields are considered unnecessary.

currents flow in the twisted loops, current must pass into and out of the strips *sideways*, and this certainly will happen if a sideways-path be afforded. This function is performed to a greater or less extent by the lead sheath.

Each passage from copper to lead will interpose extra resistance in the path of the eddy current, but by the process of manufacture the contact between the copper and lead is bound to be so intimate that it is doubtful whether this forms any effective bar to the passage of the eddy currents.

The best method to overcome this loss is, *first* to wind on the copper strips with a lay as different from that of the cores as possible, and then to apply a thin coat of paint before applying the lead sheath. This coat of paint will be amply sufficient to prevent the eddy currents leaving the copper, but should leakage occur from one of the high potential conductors, this insulation would either be instantly broken down, or failing this, would be sufficiently low to form a thoroughly good earth.

For example, if ω_1 equals the resistance per unit length of lead sheath, ω_2 that per unit length of copper earth shield, and Ω the insulation resistance of the coat of paint separating unit lengths of lead and copper sheaths, then the resistance * between lead and copper measured at one end of the cable is

$$\sqrt{\Omega(\omega_1 + \omega_2)}\,\frac{1 + \epsilon^{-2ql_1}}{1 - \epsilon^{-2ql_1}}, \quad \text{where } q = \sqrt{\frac{\omega_1 + \omega_2}{\Omega}},$$

and l_1 is the length of the cable.

If now we take a particular case and write :—

$\omega_1 = 120 \times 10^{-6}$ ohms per foot (corresponding to an area of cross section of lead sheath of ·785 □");
$\omega_2 = 39 \times 10^{-6}$ ohms per foot (corresponding to an area of ·196 □";
$\Omega = 53$ ohms (measured between 1 ft. length of lead sheath and the same length of earth shield);

then $q = 1{\cdot}73 \times 10^{-3}$; for values of l_1 greater than $\frac{3}{2q}$ we may call $\frac{1 + \epsilon^{-2ql_1}}{1 - \epsilon^{-2ql_1}}$ unity. This value of $l_1 = 866$ ft. Hence for all lengths greater than $\frac{1}{6}$th mile we could in the above case take the resistance measured at one end between copper and lead as $\sqrt{\Omega(\omega_1 + \omega_2)} = {\cdot}0916$ ohms.

* To demonstrate this, we apply between the lead sheath and earth shield a constant potential difference V, and consider the current flowing after the steady state has been reached.

Let v_1 be the potential at any point of the positive conductor, and v_2 the potential at a corresponding point of the negative conductor (*i.e.*, copper and lead respectively); if c_x be the current at any point flowing longitudinally, we have :—

$$-\frac{dv_1}{dx}\cdot\frac{1}{\omega_1} = \frac{dv_2}{dx}\cdot\frac{1}{\omega_2} = c_x \text{ and } -\frac{dc_x}{dx} = \frac{v_1 - v_2}{\Omega},$$

$$\text{or } \frac{d^2 c_x}{dx^2} = \frac{\omega_1 + \omega_2}{\Omega}\,c_x.$$

Such a low insulation as this would conduct any leakage from one of the cores direct to the earth, whereas an insulation resistance of 53 ohms between 1 ft. length of lead and copper would be an effectual bar to the circulation of eddies between them.

APPENDIX I.

DISTRIBUTION OF INDUCTION AND EDDY CURRENTS IN A LONG IRON PIPE, ENCLOSING AN ALTERNATING CURRENT.

Let $\Gamma_c = \Sigma \, \Gamma_i \sin (p_i t + e_i)$ stand for the Fourier's series representing the current in the cable, the summation being extended to all components of the current of differing frequencies.

$$p_i = 2 \pi i n, \text{ where } n \text{ is the fundamental frequency.}$$

Thus Γ_o is the amplitude in amperes of the fundamental term, and Γ_i

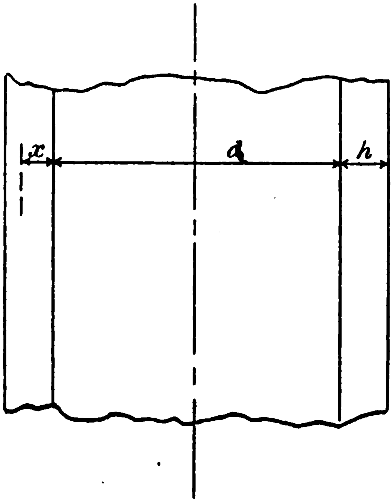


FIG. 16.

the amplitude of the term involving the frequency $i n$. The epochs denoted above by the general expression e_i will not affect the following considerations.

If the cable be of finite length we must write the solution of this equation in the form—

$$c_x = c_1 \left(\epsilon^{-qx} - \epsilon^{-q(2 l_1 - x)}\right), \quad \text{where } q = \sqrt{\frac{\omega_1 + \omega_2}{\Omega}}.$$

Hence $\quad c_o = c_1 (1 - \epsilon^{-2 q l_1})$ and $V = \Omega \, q \, c_1 (1 + \epsilon^{-2 q l_1})$.

Hence
$$\frac{V}{c_1} = \Omega \, q \left(\frac{1 + \epsilon^{-2 q l_1}}{1 - \epsilon^{-2 q l_1}}\right).$$

If the resistance be measured at any point other than at the end of the cable a smaller value will result.

Let B_x denote the induction at x in lines per sq. cm.

" σ_x denote the current density in amperes per sq. cm. of the longitudinally flowing current at x.

" L be the mean circumferential length of pipe, assumed to be the length of all the magnetic lines within the pipe, which will be more and more nearly true as the diameter of the pipe is made large in comparison with the thickness.

" h be the thickness of pipe wall in cms.

" d be the internal pipe diameter in cms, then $L = \pi(d + h)$.

" c_x denote $L\int_o^x \sigma_x \, dx$, or the total current in amperes flowing longitudinally in the hollow cylinder bounded by the interior surface of the pipe and a coaxial surface passing through x.

" v be the potential difference between two planes 1 cm. apart normal to the pipe axis.

" μ be the mean permeability.

" η stand for $4\pi\mu/10$.

" m_i stand for $\cdot 000199\sqrt{\frac{\mu i n}{\rho}}$.

" ρ be the specific resistance (electrical) of iron.

" P_i stand for $\frac{\Gamma_i m_i}{L}\sqrt{\frac{\cosh m_i h - \sinh m_i h}{\cosh m_i h + \cos m_i h}}$.

B_x, c_x, σ_x, and v are all time functions, and may therefore each be expressed as a Fourier's series; we shall accordingly denote the amplitude of the term involving the frequency $i\,n$ as $\overline{B}_{xi}$, $\bar{c}_{xi}$, etc.

There are two special cases for consideration—

(1) Where the pipe is laid in dry concrete or dry earth, so that no eddy currents leak out or leave the pipe.

(2) Where the pipe is laid in wet soil, or where the ends are for any other reason at the same potential. These two cases are represented by the conditions—

$$(1)\quad c_h = o. \qquad\qquad (2\quad \sigma_h = o.$$

The differential equations of the problem are—

$$10^8 \rho \frac{d^2 \sigma_x}{dx^2} = \eta \frac{d\sigma_x}{dt}; \qquad \eta\,\sigma_x = \frac{d B_x}{dx}.$$

From which the following are readily deducible :—

Case I.

$$(1)\quad \sigma_x = \Sigma P_i\left\{\epsilon^{m_i x}\sin(p_i t + m_i x + \phi_i) - \epsilon^{m_i(h-x)}\sin(p_i t + m_i(h - x) + \phi_i)\right\}$$

where ϕ_i is related to c_i.

From which we may write :—

$$\bar{\sigma}_{xi} = \frac{\Gamma_i m_i}{L} \sqrt{\frac{2 (\cosh m_i (h - 2x) - \cos m_i (h - 2x))}{\cosh m_i h + \cos m_i h}}.$$

The eddy-current losses per centimetre length of pipe expressed in watts are :—

$$\frac{L \rho}{2} \Sigma \int_0^h (\bar{\sigma}_{xi})^2 dx = \frac{\rho}{L} \Sigma \Gamma_i^2 m_i \frac{\sinh m_i h - \sin m_i h}{\cosh m_i h + \cos m_i h}.$$

$$(2) \quad B_x = 10^8 \rho \Sigma \frac{P_i m_i}{p_i} \left\{ \epsilon^{m_i x} (\sin - \cos)(p_i t + m_i x + \phi_i) + \epsilon^{m_i (h-x)} (\sin - \cos)(p_i t + m_i (h - x) + \phi_i) \right\}^*$$

From which we may write :—

$$\bar{B}_{xi} = \frac{\Gamma_i \eta}{L} \sqrt{\frac{\cosh m_i (h - 2x) + \cos m_i (h - 2x)}{\cosh m_i h + \cos m_i h}}.$$

$$(3) \quad v = - \rho \Sigma P_i \left\{ \sin (p_i t + \phi_i) - \epsilon^{m_i h} \sin (p_i t + m_i h + \phi_i) \right\}$$

$$(4) \quad c_{h/2} = \Sigma \frac{\Gamma_i}{\sqrt{\cosh m_i h + \cos m_i h}} (\sin - \cos)\left(p_i t + \frac{m_i h}{2} + \phi_i\right) - \Gamma_c.$$

From which we see that if h be sufficiently great, the current flowing longitudinally along the inner skin and back along the outer skin of the pipe, is at every instant equal to the current in the cable, the direction being such as to produce zero resultant magnetisation in the centre of the pipe wall.

Case II.

The expressions for σ_x and $\bar{\sigma}_{xi}$ are manifestly derivable from the corresponding expressions in the first case by writing $2h$ instead of h, whence the eddy-current loss in watts per centimetre length is :—

$$\frac{\rho}{2L} \Sigma \Gamma_i^2 m_i \frac{\sinh 2 m_i h - \sin 2 m_i h}{\cosh 2 m_i h + \cos 2 m_i h}.$$

Similarly B_x and $\bar{B}_{xi}$ are derivable from the previous corresponding expressions by making the same substitution as above, and so on.

In the case of thick pipes of correspondingly larger diameter, so that we may still, without sensible error, consider all magnetic lines within the pipe as of equal length, we have for the watts per cm. length of pipe :—

$$\frac{\rho}{L} \Sigma \Gamma_i^2 m_i. \qquad \text{(Case I.)}$$

$$\frac{\rho}{2L} \Sigma \Gamma_i^2 m_i. \qquad \text{(Case II.)}$$

* For the sake of brevity we have here adopted the form $(\sin - \cos)\,\theta$ for $\sin \theta - \cos \theta$.

It is interesting to observe in this connection that if we have a circuit made up of two single-phase cables laid parallel to one another, each in a separate pipe, the pipes being practically insulated (*e.g.*, as when laid in dry concrete), then, by electrically connecting the two pipes together at each end, we halve the hysteresis and eddy-current losses in them.

Or if we consider the 3-phase case already alluded to, where three single-core cables were drawn through three separate pipes, we should again halve the hysteresis and eddy losses in the pipes by electrically connecting them at either end. When the pipes are thus connected we have Case II., when separated, Case I. It will be observed that the eddy currents induced by each cable, flowing, let us say, up the interior surface of the pipes and back along the exterior surfaces, together form the equivalent of a 3-phase 6-line-wire eddy current system. As soon as we connect the pipes together at either end, we do the equivalent of grouping three of the return line-wires. But we know in a 3-phase system no current would flow back along this common wire, hence we see in a very simple manner that we should halve the eddy C^2R loss, and with it the hysteresis loss, in the manner above described.

APPENDIX II.

In the following the magnetic fields due to various systems of straight parallel conductors are considered, it being assumed that the conductors are circular in section, and that the distribution of current over the cross-section of each conductor is a function of the distance from the axis of the conductor only. Our ground for this assumption has already been explained.

Case I.

Two parallel conductors, with current flowing up one and down the other.

We have $\frac{r_1}{r_2}$ = constant = z_i for all points in the i^{th} line of force.

In polar co-ordinates we have—

$$z_i^2 = \frac{\zeta^2 + r_3^2 - 2\,\zeta\, r_3 \cos\phi}{(\zeta + b)^2 + r_3^2 - 2\,(\zeta + b)\, r_3 \cos\phi}.$$

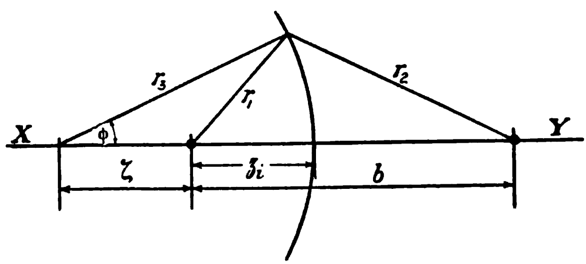


FIG. 17.

If we write $z_i^2(\zeta + b) = \zeta$, or $\zeta = z_i^2 b/(1 - z_i^2)$, z_i is independent of ϕ, hence we see that the i^{th} line of force is a circle whose radius is $z_i b/(1 - z_i^2)$, the centre being situated on the axis X Y. It is sometimes convenient to express this in terms of the intercept ξ_i—

$$\text{It is, Radius} = \frac{\xi_i (b - \xi_i)}{b - 2\xi_i}.$$

It is to be observed that the law $\frac{2c}{10} \log \frac{r_1}{r_2} = k$ only holds true for those portions of the lines of force external to the conductors. If we take a point inside the conductor at a distance r_1 from the centre, the total number of lines within the conductor which surround the point is $\frac{c}{10}\left(1 - \frac{r_1^2}{\beta^2}\right)$ where $\beta =$ the outside radius of the conductor, c being, as before, the current in amperes. For points inside the conductors we have therefore in the 2-conductor case :—

$$\left.\begin{array}{l} +\frac{c}{10}\left(2 \log \frac{r_2}{\beta} + 1 - \frac{r_1^2}{\beta^2}\right) \\ -\frac{c}{10}\left(2 \log \frac{r_1}{\beta} + 1 - \frac{r_2^2}{\beta^2}\right) \end{array}\right\} = k,$$

which enables us to construct the complete field of force both inside and outside the conductors.

Case II.

Three parallel conductors carrying currents c_1, c_2, c_3, where $c_1 + c_2 + c_3 = 0$ at every instant.

We have for external points—

$$-\frac{1}{5}(c_1 \log r_1 + c_2 \log r_2 + c_3 \log r_3) = k.$$

If we take a particular case, and write $c_1 = -2\,c_2 = -2\,c_3$, we have—

$$-\frac{c_1}{5} \log \frac{r_1}{\sqrt{r_2 r_3}} = k.$$

The line of force which runs out to infinity, separating the positive from the negative fields of force, is given by the condition $k = 0$,

$$\text{or} \quad r_1^2 = r_2 r_3.$$

For points inside the conductors we have :—

$$\left.\begin{array}{l} -\frac{c_1}{10}\left(2 \log \frac{\beta}{\sqrt{r_2 r_3}} - 1 + \frac{r_1^2}{\beta^2}\right) \\ -\frac{c_1}{10}\left(2 \log \frac{r_1}{\sqrt{\beta r_3}} + \frac{1}{2} - \frac{r_2^2}{2\beta^2}\right) \\ -\frac{c_1}{10}\left(2 \log \frac{r_1}{\sqrt{\beta r_2}} + \frac{1}{2} - \frac{r_3^2}{2\beta^2}\right) \end{array}\right\} = k.$$

Case III.

Two-phase cable, consisting of two circular cores enclosed in a sheath forming the common conductor.

For external points we have :—

$$\frac{2\,c}{10} \log \frac{\sqrt{r_2\, r_3}}{r_1} = k,$$

and for internal points (except for points inside either conductor), we have :—

$$\frac{2\,c}{10} \log \frac{\sqrt{r_2\, r_3}}{\Delta},$$

and so on.

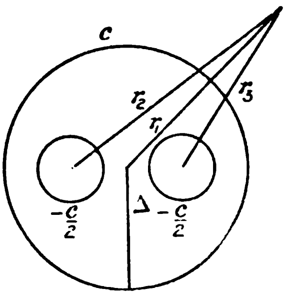


FIG. 18.

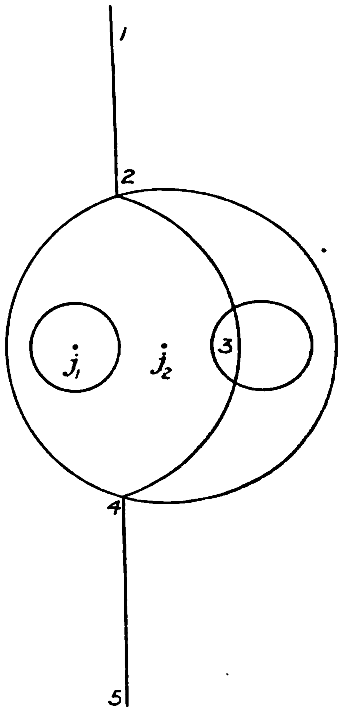


FIG. 19.

If the current in, say, the right-hand core is zero, in the outer c, and in the left-hand inner $-c$, then the external field of force is that due to two conductors at the points j_1 and j_2 respectively, while within the magnetic lines are concentric circles with centre at j_1, Fig. 19.

The line separating the positive from the negative field will therefore be *1, 2, 3, 4, 5*, being a straight line externally, and an arc of a circle of radius Δ internally,

In dealing with systems of circular conductors we usually find that the nucleus of the field of force (or the point enclosed by the maximum number of lines) is displaced from the centre of the conductor.

For example, in the two-core case the positions of the nuclei are determined by the value of r_2 that renders

$$2 \log \frac{r_2 + b}{\beta} - \frac{r_2^2}{\beta^2} \text{ a maximum.}$$

This is $$r_2 = \pm \sqrt{\beta^2 + \frac{b^2}{4}} - \frac{b}{2}.$$

Whereas if the current in each conductor be in the same direction which occurs in the two-phase case already considered—

$$r_2 = \pm \sqrt{\frac{b^2}{4} - \beta^2} - \frac{b}{2},$$

b being the distance between the centres of the two conductors.

Cores of other than circular cross sections: In dealing with cables having segmental-shaped cores, or any shape other than circular, we must use the expression $\frac{1}{A} \Sigma \delta A \log_\epsilon r$ instead of merely $\log_\epsilon r_1$, etc., as above; that is to say, instead of merely taking the whole current in the core as concentrated at the axis, and taking the log. of the distance from the core-centre to the point in question, we must consider elements of area separately, taking the sum of the logarithm of the distance multiplied by each little element of area, divided by the total area of cross-section A.

The CHAIRMAN: I have to propose a very hearty vote of thanks to Mr. Field for his very able and very interesting paper. The Chairman.

Mr. G. L. ADDENBROOKE (*communicated*): I cannot help feeling sorry that there was practically no opportunity of discussing Mr. Field's paper, as it deals with matters of very great practical importance. The paper was entirely theoretical, but in this particular line I think this is what has been chiefly wanted for some time. There have been reports by different experimenters that they have found traces of losses such as Mr. Field describes, but the matter being a complicated one these reports have hitherto lacked coherence, and there being a possibility of getting losses from three distinct sources, namely, dielectric hysteresis, eddy currents, and hysteresis in the iron sheath, it has been difficult to distinguish what proportion of the effects observed has been due to one or other of these different causes. Mr. Addenbrooke.

In the discussion on Messrs. Constable and Fawssett's paper, I alluded to some experiments I undertook at Messrs. W. T. Henley's Telegraph Works nearly two and a half years ago. Though these experiments were intended chiefly to go into the question of dielectric hysteresis, nevertheless in the course of the experiments effects were observed of the character alluded to by Mr. Field. For instance, Mr. Field puts the question of currents in the lead sheath. Now in the experi-

Mr. Addenbrooke.

ments alluded to, one set of cables had a bare lead sheath and were coiled on drums. An attempt was made to measure the dielectric losses in this cable between the inner conductor—the cable being a concentric one—and the lead sheath. The losses were, however, found to be so considerable that it was evidently useless to continue the experiment in this form. The lead evidently acted as the secondary of a transformer sufficiently for heavy and considerable losses to take place in this. This evidently points to the fact that lead-covered cables carrying alternating currents should not be laid in metallic connection with conductors which may form a return circuit.

The next point which turned up was as follows:—Several measurements having been made on lengths of cable which were unarmoured, an armoured length was substituted, and in this the losses were uniformly higher than in similar cable made of the same materials but which was unarmoured, the cables being concentric in both cases and the tests taking place between two conductors.

The order of the results was about as follows:—At 3,000 volts the power-factor was 1·45 per cent., while for a similar voltage and periodicity with armoured cable the power-factor was 1·62 per cent. Experiments were made at other voltages with somewhat similar results. The effect is not large under these circumstances, but then with concentric cables the external field must be small. I had no opportunity of making a similar set of tests on three-phase cable under similar circumstances, where one would expect the effects to be somewhat greater.

Of course, in these experiments the current flowing through the cable was merely the current used for electrostatically charging it, and consequently the effect would be very small. With the actual currents flowing in practice through the cable, it is quite possible that the effects might be very appreciable. The only way to determine them, it seems to me, would be to take a length of cable having a non-inductive resistance at one end in which the energy of the current passed through the cable would be dissipated. If then a steady alternating current were passed through the cable and simultaneous measurements could be taken at both ends of the current and of the watts lost, deducting the calculable loss in the conductor of the cable, it ought to be possible to arrive at any other losses which might take place.

I would be happy to give any assistance in my power in the conducting of such a set of experiments, as I think it would be for the general benefit of the industry that they should be made.

Mr. Fawssett.

Mr. E. FAWSSETT (*communicated*): As joint-author with Mr. Constable of the paper to which Mr. Field is kind enough to refer, I should like to compliment him on the clearness of his paper, and on the admirable way in which he has dealt with an interesting subject. Many diverse opinions were expressed in the discussion on our paper as to the real cause of the external field, which has led me to give the subject some further consideration. The effect I observed on the cables at Croydon was much the most intense on the telephone wire contiguous to our No. 7 feeder, which it will be remembered was the anomalous V.B. cable. It is well known that the conductors of these

cables sink in the insulation, and as the inner gets hotter than the outer, and moreover offers less surface to the dielectric, it would no doubt sink further than the outer, resulting in an *eccentricity without twist*, which I am convinced was the chief cause of the trouble. In other cases I think the most usual cause is a leakage to earth at the substation causing the "inner" and "outer" currents to be slightly out of balance. Mr. Fawssett.

Mr. M. B. FIELD (*in reply*): I wish to thank Messrs. Addenbrooke and Fawssett for the remarks they have been kind enough to communicate to the Journal on the subject of the foregoing paper. Mr. Field.

The question has been asked by several, whether any portion of the so-called dielectric hysteresis losses in cables can be accounted for by eddies in the lead sheaths. I am of opinion that this is certainly not the case; dielectric losses are measured with the charging current only flowing into the cable. The sheath losses have been calculated in the paper assuming the cables fully loaded, and even then, for ordinary-sized cables, are small. The sheath loss, however, is proportional to the square of the current transmitted, and therefore will be utterly negligible if only produced by the charging current. In the discussion of Messrs. Constable and Fawssett's recent paper I pointed out that the whole of the so-called dielectric loss *as measured* was not a dielectric loss at all, but that a portion of the measured loss had its seat in the copper core, and was due to the C^2R loss of the charging current. An example was worked out, showing that this component of the loss is an exceedingly small one. Now in the foregoing paper it has been pointed out that the sheath loss may be allowed for by assuming the specific resistance of the core material is somewhat increased, just as the loss due to "skin effect" in a round conductor may be allowed for by multiplying the actual resistance of the conductor by a coefficient, and assuming the result to be the virtual resistance. From the examples worked out, however, it is evident that for ordinary-sized cables the virtual increase of specific resistance to account for sheath loss is small, and therefore, seeing that the C^2R component of the so-called dielectric loss is already very small, it is difficult to see how the sheath loss can account for any appreciable proportion of the measured dielectric loss. The remarks of Mr. Addenbrooke, however, are of very great interest, and should form the basis of a very profitable investigation. Very little has been said in the paper on the effect of armouring multiple-core power-cables. Since the paper was read, however, Mr. G. F. C. Searle, of the Cavendish Laboratory, Cambridge, has been considering this question mathematically. It is of considerable interest to engineers, and I trust we may look for a publication on the subject shortly.

Mr. Fawssett's hypothesis *re* the telephonic disturbance due to the V.B. concentric cable at Croydon is very suggestive, and seems quite feasible.

BIRMINGHAM LOCAL SECTION.

THE EQUIPMENT OF AN ENGINE TEST-HOUSE.

By R. K. Morcom, Associate Member.

(*Paper read at Meeting of Section, February* 17, 1904.)

The days of broad guarantees of coal consumption of a plant per month or per annum have now passed, and the era of specialised testing has been inaugurated by modern competition. Nowadays boilers, engines, generators, and motors must all be proved to fulfil the specification as to efficiency and reliability, and it is on the closeness with which the results obtained approach the guaranteed figures that the justification of an enterprise often depends.

The value of the experience gained by tests is so great that all progressive manufacturers lay down more or less extensive testing plants for their own use, and so it is only natural that their test-houses should also be used to demonstrate guarantees, and so ensure that time shall not be wasted on site, and to avoid the inconvenience to a station engineer of having his station turned into an experimental department.

A brief account of the evolution of a plant for testing combined sets for electricity stations, and of some of the more interesting results obtained, is the object of this paper.

In getting the necessary apparatus the following requirements had to be met:—

The units to be tested ranged in size from 75 to 1,250 H.P., running condensing or non-condensing, with steam pressures from 80 lbs. to 250 lbs., and degrees of superheat up to 350° F. above saturation point.

The voltage might be anything from 60 to 6,000, and the current anything from 10 to 2,000 amperes, either in direct current or in single or polyphase alternating current of various frequencies.

The sets might have to run at full load, light loads, and varying loads. Regulation tests of the dynamo and governing tests of the engine would also be generally required. Add to this the fact that only a limited space would be allotted, and as rapid changes from one set to another were necessary, the complication of the problem is obvious.

A testing plant had to be evolved to meet the above requirements, which should be accurate without being too costly, and which should be satisfactory to the expert, and yet easy to explain to the inexperienced.

In the following paragraph is given an account of a modern engine test-house intended to meet the above requirements satisfactorily, without neglecting the important question of cheap working costs.

Steam is raised by four water-tube boilers, capable of producing 20,000 lbs. of steam per hour. It is carried either direct to the engine or through a separately-fired superheater. Steam-dryers are fitted in the flues of two of the boilers. Analyses of gases and fuel consumptions are taken periodically, and everything possible is done to keep the steam-raising costs low.

The range is designed to supply eight testing berths. It is divided into two sections, each of which can be isolated with one or more boilers in case tests at different pressures are run simultaneously. Reducing valves have been avoided, owing to the fact that the very trying conditions of varying pressure and temperature would probably render them a source of trouble.

The test-plates are of the usual grid type on solid concrete foundations, and pits are arranged to accommodate big generators. The engines are coupled to the range by means of steel bends and matching pieces, each standard engine having its own series of piping. Flexible piping and other similar devices have been found unsuitable for test-house wear and tear. Difficulty has been found in providing lagging for the temporary pipes ; the most satisfactory so far has been a large diameter asbestos rope, with which considerable lengths can be expeditiously lagged.

Temperature Tests.—A thermometer is fitted into the steam-pipe leading to each engine, and the temperature of the steam is adjusted to meet the requirements of the inspecting engineer.

The first arrangement used for measuring this temperature was a steel tube or cup, closed at one end, and arranged to screw into the steam-pipe at any convenient place close to the engine. The cup was filled with mercury, and an ordinary high-reading glass thermometer dropped into the mercury. As the lower portion of the cup extended well down into the steam space, the thermometer gave a fairly close approximation to the actual temperature of the steam. This method is adopted by a good many makers who supply thermometers for reading steam temperatures, the only difference being that the glass thermometer is secured in the cup, and generally provided with a metal cover to protect the glass from injury. This method, however, is not sufficiently accurate, as the thermometer always gives a reading lower than the actual temperature, owing to a certain amount of heat being lost by conduction from the cup to the comparatively cool steam-pipe.

Another way of indicating the steam temperature is by means of a mercury steel pyrometer, which indicates the temperature by a pointer on a dial face, and has much the same appearance as an ordinary pressure gauge. It is actuated by the expansion of mercury in a steel tube reacting on a spring. This type of instrument need not itself be attached directly to the steam-pipes ; it may be fixed in any position in the engine-room, and connected by a fine steel tube containing any convenient medium to transmit the pressure to the spring. It is useful as an indicator to the engine attendant, but it is troublesome to calibrate, and requires frequent correction.

Professor Burstall suggested a platinum-wire pyrometer, but this

was frequently broken by the rush of steam, and was too delicate for a works test-house.

The present arrangement is a thin steel tube, screwed well into the steam-pipe through a stuffing-box, so that an asbestos packing may insulate it from the steam-pipe. Oil is used in the tube instead of mercury, as it is found slightly more accurate; the mercury also boils away at high temperatures.

Exhaust.—Exhaust steam is passed into a range connected to three surface condensers, separated by middling valves. The back pressure is adjusted to the specified amount from the lowest the plant can register up to any specified amount. The exhaust range has to be extremely adaptable, as engines are often running round unloaded for one cause or another, while water consumptions are being taken on others on load. Accordingly every branch is 3-wayed, going to the engine, an atmospheric main, and to the condenser main. At every point where water may collect a drain has been fitted, as water returning from the exhaust has occasionally been found troublesome. The larger engines are coupled up by large cast-iron pipes, the smaller ones with flexible piping.

The air-pump discharge is passed into tanks attached to Avery balances, on which the amount of water delivered in any given interval is weighed and announced by electric bell to any suitable point. Open-ended flushing valves are provided to these tanks in order that any leakage can be immediately detected or rectified.

The actual taking of the water consumptions varies in different test-houses, so a brief description of the method adopted in the one under consideration may not be out of place. Before attempting to take a measurement under certain fixed conditions of load and steam, the engine should be run under those conditions for a sufficient time to ensure its having reached its proper temperature throughout. The time varies from a quarter of an hour to an hour. If this point is neglected, anomalous results are apt to be obtained. This also has a bearing on what may be called traction-load results with a varying load. It has been found that short measurements taken at different loads dropping from full load by steps down to no load at, say, ten minutes' intervals, always gives better results than when taken on an up-grade.

It is possible to conceive that with the same mean load on the same size engine certain load curves will for this reason give better results than others.

All cylinder drains should be closed, and the ends of the drain pipes should be inspected for leakage, unless they are coupled into the engine exhaust pipe. The valve from the condensed water weigh-tank should be shut, and the sliding weight of the balance set at a fixed point on the arm. As soon as the weight is balanced, the arm on its upward swing makes an electric bell circuit, and the man at the load-board carefully notes the time and load. The slide-weight is then moved on sufficiently to give a two minutes' interval before the next ring, when the process is repeated. A complete log of steam pressure, temperature, etc., are taken, say, at every third reading. In this way over a

half-hour's tank results can be obtained with quite as great accuracy as would be obtained by an arduous six hours' water consumption. The idea that a lengthy measurement of condensed water is necessary is really due to the fact that a confusion exists in some people's minds between measurements of feed water and condensed water.

Brake Test.—Tests are often run on the water brake if the dynamo is not to hand. A series of brakes is kept to suit different sizes, the "Heenan and Froude" pattern being the one adopted. The beauty of this brake, from the inspecting engineer's standpoint, is that, whatever else it may be doing, the engine is certainly lifting a certain weight at a certain radius. The type is too well known to require any description here.

As a check on the readings, either brake or electrical, and also when comparing B.H.P. with E.H.P., the indicator is always used. But too much reliance on the readings of this instrument may lead to trouble, especially in high-speed work. Cards taken on the same load by experienced and inexperienced operators often vary as much as 5 per cent.

The efficiency of a well-constructed quick-revolution engine is so high, that unless practically the whole I.H.P. is registered absurd results are recorded, whereas a similar fault on a less efficient engine would be unnoticed. For this reason separate indicators are used, both top and bottom, with full bore fittings right into the cylinders. The indicators are continually calibrated under steam, and all cards are taken by an expert operator. In this way the highest accuracy is ensured, and the indicator becomes a useful check on other figures. An interesting point in high-speed engine indicating has been demonstrated, viz., that the oscillations always associated with the cards are actually present in the steam, and are not due to indicator inertia.

After trials of a large number of instruments, and consideration of objections raised by grumblers thereat, the following equipment for testing the electrical side of the plant has been arranged :—

Ammeters.—For direct current shunted instruments of the "Weston" and "Solenoid" types are used. For alternating current double-range hot-wire ammeters are adopted, except for very high voltages, when suspended coil dynamometers have proved more serviceable. The instruments here detailed for alternating current are, of course, available for direct current also. As a calibrating instrument, a large "Siemens" dynamometer with reversing switch is found reliable.

Voltmeters.—For direct current the "Weston" type has also been chosen, being fitted with a volt-reducing box to give a very big range. For alternating work vertical scale static instruments are used. For calibration a wide-ranged horizontal scale "Kelvin" instrument has been adopted.

Wattmeters.—The hardest instrument to come to a decision about is undoubtedly a wattmeter for alternating current. Every engineer seems to have his own views on the matter, and an instrument that has much to recommend it to the practical man is often condemned for some theoretical defect. The instruments finally adopted in the test-house under consideration are of the suspended coil type, both

direct and zero reading. The current range is capable of alteration by putting the current coils in series or parallel, and the volt range is also variable by means of resistances.

Potentiometers.—In experimenting with a potentiometer, the fact that the works' foundations were of a light character rendered the mirror galvanometer too delicate an instrument, as the vibration of the cranes made the spot very elusive. This difficulty might have been overcome by the use of felt pads, or some form of vibration damper, but another reason put this highly adaptable and accurate instrument out of court. This reason was an appreciation of the value of simplicity in inspiring confidence in the tests. It was thought best to contrive so that any one could follow and check every figure, even the most inexperienced assistant whom it might be convenient for a chief engineer to send down; and from a manufacturer's point of view, also, so much must be taken on trust where time is important that a careless assistant may vitiate a whole series of results when working with an instrument which does not give readings without manipulation.

Water Resistance.—After considerable trouble and expense in connection with wire resistances, both in wooden and iron frames, a form of water resistance for taking up the load has been devised. The poles are of iron, arranged in wooden tanks. Water from a neighbouring canal is passed continually through the tanks by a bye-pass on the condenser circulating pump, and flows out over a weir. The poles are connected to a load-adjusting switchboard, and can be coupled into the load in many combinations. Three tanks are used for different ranges of voltages, and these ranges are further divided by adjustments of the outflow from the tank. Specially subdivided tanks are used for polyphase work.

The first experience when using a water resistance was not very satisfactory. The apparatus consisted of an iron tank about 3 ft. wide and 6 ft. long, with two large iron plates for the electrodes. This tank did not last very long, for the current, as well as passing from plate to plate, found a shorter passage by way of the sides and bottom of the tank. An improvement of this arrangement was a large wooden tank, 4 ft. wide by 10 ft. long, and about 4 ft. deep. Into this were fitted four hollow cone-shape castings, large end upwards. Inside each of these cones was a smaller one, suspended from above on a screwed spindle and hand-wheel. The outer cone was coupled to one terminal of the dynamo on test, and the inner through a flexible lead to the other terminal. Load could then be varied by raising or lowering the inner cone on the screwed spindle. It was necessary to keep the water-level a little higher than the top edge of the outer cone, so that the heated water in the space between the cones might rise naturally and flow away. This arrangement gave very satisfactory results; in fact, some cones are still in use which were fitted about eighteen months ago.

For higher voltages it was proposed to use a metal rod dipping into the water at the centre of the cone, but the conducting area of water to the outer cone was too large, and the length of water resistance too

small for many machines. Accordingly, a wooden trough of small cross-section and great length was designed for high-voltage work.

The use of wooden troughs did away with the need for conical poles, and it is now found more useful to substitute iron plates fixed at the top to flexible terminals, and movable on insulated rollers along wooden runners. The load can thus be varied by sliding the plates along so that the cross-section between them is varied. By using a considerable number of smallish plates a very flexible load is obtained, and if care be taken with the circulating arrangements a very steady load results.

Switchboards.—These are of two types. Those of the one type are purely load boards, and are placed close against the load tanks. They are arranged to give any required fraction of the load by cutting out sections of the poles of the water resistance.

The other boards are instrument boards, and are portable. They each contain a complete equipment of instruments and switches suited to the class of machine for which they are used. Special boards are provided for continuous current and high and low voltage alternating current; these latter are made suitable for three-phase work. A description of the three-phase low-voltage board will be characteristic:—

The board is made of a stout wooden frame, with an ample base, which is arranged for bolting down if necessary. The instruments and switches are mounted on the front and side faces on slate slabs. In the space contained by the wings of the board at the back are arranged all the required connections and terminals. There are three hot-wire ammeters, one static voltmeter, with three-way switch, and one large three-phase switch for the main circuit. On a shelf projecting below the ammeters are placed two wattmeters of the suspended coil type. Lamps lit by the machine on test are arranged over each instrument. They serve not only to light up the dials, but afford information to a distance. The auxiliary instruments for the exciting circuit are fitted on the wings. The whole board with instruments and connections can be lifted by a crane.

The cables are being laid in troughs, with a junction box to each test-berth, all being connected to the load boards.

Besides the supply of low-reading ammeters for shunt and exciting, circuit reading portable rheostats are kept, as it is generally inconvenient to run a generator with its own regulating resistance. These have two sliding contacts on the top for coarse or fine adjustment, and the coils are contained in stout angle-iron frames, shielded with perforated sheet steel. They are stronger and have a larger range than those usually supplied with the machines.

After the various trials, which can be run light, and which by deduction based on previous records, can be made to give most of the information required about the engine, the dynamo is coupled up to the load.

The portable switchboard is placed in front of the engine and connected to the dynamo and junction-box. The proper arrangements of the load board are then made, the machine excited and loaded up, and

all the required preliminary trials made. After any defects discovered by these runs have been put right, the set is ready for its official tests.

The usual course is a six hours' run at full load, after which dynamo temperatures, etc., are taken. Then the governor is tested, and then any light load or special trials are made.

Water consumptions are taken periodically. In recording these great care must be taken to have all readings taken that are necessary for accuracy. Steam pressure and temperature, vacuum, revolutions and load must be carefully recorded over the interval during which the condensed water is being weighed. Indicator cards should be taken during each consumption test as a check on the load-measuring instruments. Simultaneous all-round readings should be arranged by signal, in order to give the right efficiency, whenever a set of cards is taken.

After the official trial further small details are rectified and re-tested, and the set is ready for overhaul and despatch.

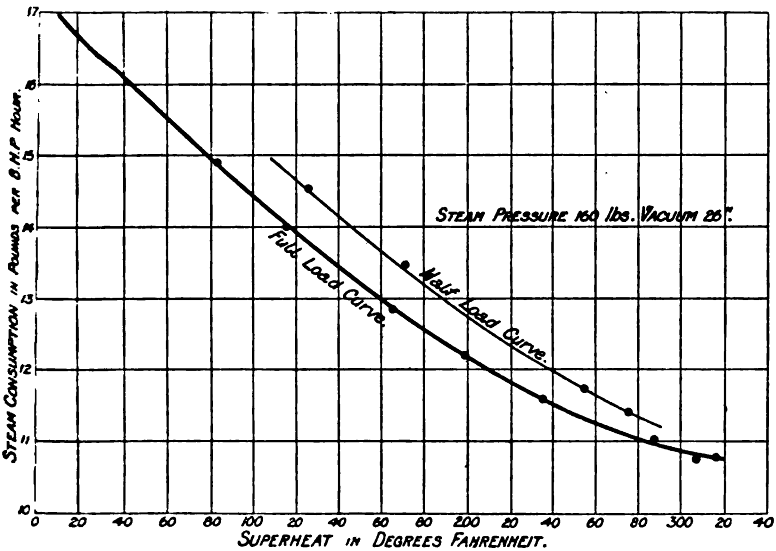
Preliminary and official trials are often utilised to give information on small points of design, such as packing, governors, oil service details and other matters. New gauges, instruments, jointing materials and lagging are also frequently under test. When it is impossible or inadmissible to run such experiments on preliminary or official trials, special trials have to be run for the purpose. These points are, of course, of great importance to the designers of engines, but though the results may be appreciated by the users, the experiments leading up to the improvements are not of the same interest. The special tests which excite most interest are those which bear on engine performance, and a brief account of some recent trials will serve to show the type of results obtained in a modern test-house.

Superheating.—The benefit due to superheating has long been recognised, but what that benefit amounts to in practice still seems very doubtful to many. On an engine properly designed to run under superheated steam conditions full advantage is taken of the improved economy with but little extra trouble in running. It is only in using superheat on an engine quite unsuited for the purpose that those troubles are experienced which in so many cases prejudice engineers against elevated temperatures.

Another point is sometimes brought forward, that as clearance for expansion must be allowed in the pistons and valves of an engine designed for superheat, so if the superheat fall the engine will be very extravagant of fuel. Experiments have been run which prove that this is a mistaken notion. An engine designed to run with 250 degrees superheat has been tested with dry steam at saturation temperature, and the result shows that with these valves and pistons the engine is only 2·1 per cent. less economical than when fitted with valves and pistons designed for ordinary conditions.

Superheat water consumption curves are given in the diagram from a three-cylinder triple engine of 200 k.w. capacity. Results are given at full and half loads. The trials were run on the brake at 160 lbs. steam pressure and 26 inches of vacuum. It will be seen that the percentage of improvement for any given rise in temperature is

approximately the same at full and half loads. The gain due to 200 degrees of superheat is here seen to be 41 per cent. On a given type of engine the curves obtained are very similar for both large and small sizes.



The actual gain due to superheat is, of course, less than this, as extra lubrication and increased fuel consumption are required. The increased cost of oil for cylinder lubrication amounts to about 0·04 pence per 100 H.P. hour, and is therefore a very small item. Fuel consumption trials run on a 522 B.H.P. triple expansion engine with 160 lbs. pressure and 26 in. vacuum gave the following figures :—

Trial (1). Fuel per hour with saturated steam ... 1,193 lbs.
" (2). " " in boilers with superheat 833 "
" " in superheater to give a temperature of 600 degrees ... 173 "

Accordingly the gain in fuel is 19 per cent. The fuel was slack of poor evaporative value.

It may be mentioned that the superheater was very lightly loaded, and that the lagging of the steam pipe was not so good as it might have been. Allowing for these points, it seems that a saving of, say, 25 per cent. might be expected by superheating to 600 degrees.

Another interesting trial taken on a 120 B.H.P. compound engine at 450 revolutions per minute was on the influence of forced lubrication on the indicated horse-power at light loads. The engine was run free, and friction cards taken with oil pressure of 30 lbs., 5 lbs. and 0 lb. The I.H.P.'s in each case were 2·128, 2·409 and 3·333 respectively.

This is interesting as showing that a great increase in oil pressure will not bring a correspondingly big advantage.

Trials on such points as the effect of bye-passing the steam, on variable expansion governing, and many other points of the sort might be quoted, but the results are not of sufficient general interest or orginality to warrant their inclusion here.

A testing department is always accumulating results, and every result is entered up in carefully compiled history books, anomalous figures are remarked on and if possible explained, and curves illustrating various points are frequently made. This mass of information is necessarily largely unpublished, and the public only hear of the work of those numerous well-equipped laboratories when some improvement is put before them in a fully-fledged condition. Probably much of the information is not used to the full, and doubtless there are many experiments made in engineering colleges and institutions to elucidate mysteries, when all the time the solution is lying in some manufacturer's record book.

Mr. Lea. Mr. HENRY LEA (*Chairman*): In proposing a vote of thanks to Mr. Morcom for his paper, I should like to say that without any manner of doubt we all feel very much indebted to him for having presented us with a paper of such a very practical type, being in fact the boiling down of many years' experience with testing apparatus at Messrs. Snelling and Morcom's works, the cost of which apparatus from beginning to end must have run into many thousand pounds.

On p. 966 Morcom describes the means adopted for taking the temperature of the steam passing to the engines under test, and he advocates the use of mercurial thermometers immersed in oil contained in cups made of thin steel, in preference to platinum wire pyrometers, which he says were frequently broken by the rush of steam, and are too delicate for a works test-house. This seems to imply that the bare platinum wire was exposed to the rush of steam. I would suggest that, if Mr. Morcom had exposed the bulbs of his mercurial thermometers in a similar way to the rush of steam, they would have been blown off one after another, and would have proved quite useless. On the other hand, I suggest that, if he were to enclose his platinum wire in a protecting tube having only one or two very small holes in it to allow the steam to obtain access to the platinum wire, he would place the platinum wire thermometer under the same conditions of safety as he is compelled to give to the mercurial thermometer, and no further trouble would ensue. My experience with mercurial thermometers immersed in cups is that they do not register correctly the full temperature of the steam and that, in that respect, a platinum wire thermometer properly protected from mechanical injury would be quite a superior instrument.

On p. 966 Mr. Morcom says that, in the way described, half-hour tank results can be obtained with quite as great accuracy as would be obtained by an arduous six hours' water-consumption test, and he calls attention to a confusion which may exist in some minds between measurements of feed-water and measurements of condensed water.

There is no doubt that this observation is perfectly correct, but the objects of a six or eight or ten hours' test are not confined to the measurement of condensed water, but relate generally to the behaviour of the dynamo and to its capability of working at full load or at a specified amount of overload without the temperature of its armature commutator and field coils rising beyond the specified amount. If, then, a prolonged test is necessary from this point of view, there is no particular reason why the consumption of steam should not be ascertained by weighings of condensed water extending over an equal lenghth of time. Mr. Lea.

On p. 967 Mr. Morcom also refers to the use of the indicator. I must confess that the older I get, the less I feel disposed to place much reliance on indicator cards. I once saw a list drawn up by an expert of the number of different ways in which an indicator card could be caused to show what was not going on in the engine, and, if I remember rightly, there were two hundred different reasons why an indicator should give false results. Even if, and when, these two hundred reasons had been eliminated by the use of excessive and unusual skill, there remains the fact that the diagram itself is drawn with a pointed wire which makes a more or less thick line. If you draw a fairly firm line with a fairly sharp pencil on a piece of paper, you will find that it may easily measure $\frac{1}{50}$th of an inch in thickness. Now, if you take a rectangle 2 in. long $\times$ 1 in. wide, and calculate the difference between the area of this rectangle inside and outside the thickness of the pencil line, you will find that with a line $\frac{1}{50}$th of an inch thick, the difference amounts to 3 per cent.

I suppose that, at the hands of some inspectors, if the contract efficiency between I.H.P. and E.H.P. were 86 per cent. and the actual trial showed 83 per cent., the inspector would be inclined to condemn the plant, or to suggest that there should be a reduction in the price in consequence of the 3 per cent. lower efficiency, whereas, as you see, the thickness of the line of the indicator diagram in the hands of different assistants appointed to measure the area of the diagram might account for the 3 per cent. in dispute.

I regard indicator diagrams as invaluable for valve setting and as methods of measurements of power where no other methods are available, but, for testing steam dynamos, I should for my part be quite content to ignore the indicator diagram altogether, and to take the result in lbs. of water per k.w., the measurements of which units are capable of being made with far more accuracy than measurements obtained by indicator diagrams.

On p. 968 Mr. Morcom refers to potentiometers. Personally, I have such a great admiration and respect for the potentiometer that I am sorry to find that Mr. Morcom feels compelled to advocate other forms of measuring instruments for electrical purposes. The reason that he gives for his view is possibly worth consideration, viz., that even the most inexperienced assistant can follow and check every figure; but I cannot help thinking that, when important tests are being carried out of electric generating plants costing large sums of money, a much better plan would be to send down a really experienced assistant, who

Mr. Lea. would rejoice to find that so accurate and reliable an instrument as a potentiometer was at his disposal for measuring the results of the test.

With regard to water resistances, I should be glad if Mr. Morcom would inform us as to what voltage and rate of current the wooden tank which he mentions, 4 feet wide, 4 feet deep, and 10 feet long can be used.

Finally, on p. 970 Mr. Morcom refers to the subject of superheating, and the curve which he gives on p. 971 shows a symmetrical improvement in steam consumption from about 10° of superheat up to 320°. This is hardly what I should have expected. I have made some laboratory tests on this subject, and I have found that the first 40° or 50° F. of superheat account for an enormous reduction in steam consumption where the valves and pistons of the engine are at all leaky. In some of my tests, 40° F. of superheat at the pressure of 60 lbs. per square inch reduced the amount of leakage by 45 per cent., which to my surprise was not materially further reduced by any increase in superheat up to 100° F. The beneficial effect of superheated steam in an engine may, therefore, I conclude, be divided into two parts: namely, first the effect of reducing the amount of steam passing through leaky valves or pistons, and second the more economical behaviour of the superheated steam in the engine, irrespective of the amount of leakage. I should imagine that there are in existence few engines which do not leak to some extent, and a large majority which leak very badly. All of them would be benefited by about 50° F. of superheat, the more leaky ones to an extent which is almost incredible, as I proved in the case of a high-speed set of 200 H.P. which I knew was in a leaky condition, and of which the electrical output went up exactly 100 per cent. in relation to the weight of coal consumed, when the steam at the engine was superheated only from 20° to 30° F.

Mr. Holden. Mr. S. H. HOLDEN said he had had a good deal of experience of Weston instruments of the standard horizontal type, and, while he believed they were about the best that were to be got, he had not found that they could be trusted altogether without re-calibration. With regard to wattmeters, he found the Kelvin balance very good and generally trusted by inspectors. He should like to know what results Mr. Morcom found. Both the Kelvin and Swinburne instruments suffered to some extent from the fact that they were not direct-reading. A direct-reading wattmeter which did not require a spring to be moved or weight lifted would be a very great convenience. Potentiometers, he agreed, were valuable instruments, but they required to be in very good hands, or it was possible to make enormous mistakes with them. His experience of inspectors sent by consulting engineers corresponded with that of Mr. Morcom. In some cases the inspection was almost a farce. There were exceptions, but in any case the inspector had to take for granted that the instruments provided were reliable.

Mr. Reynolds. Mr. E. A. REYNOLDS said he thought one of the chief difficulties engineers had to contend with in laying out a test-house for combined

sets was in the arrangement of the steam piping, in the means of conducting the load from the machine, and in connecting up the machines to the instruments. At the test-house of which he had most experience, that of Willans & Robinson, Rugby, they had very much the same sort of apparatus for connecting up the steam ranges as Mr. Morcom had described. They had found, as he had, that flexible pipes were quite out of the question, as they would not stand the wear of a test-house. The way they connected up differed slightly from Mr. Morcom's method, in that their instruments were fixed. There were permanent leads coming down to pillars near every machine, so that the only thing they had to do when a machine came on the bed was to connect up the leads on to the pillars, and the instruments were then ready. In the same way, they had permanent leads for the load. With regard to the condensers, they had found there was a large loss of vacuum whenever they had a bend or an angle in the pipe. With condensers fixed, it seemed to him they must have rather a low vacuum as the ordinary working vacuum in the engine, and, if so, what allowance did they make to get the guarantees of 27 and 28 in vacuum? As to the indicating, of course an indicator to give any reliable result at all must be in the hands of an experienced operator. If the operator was experienced, and the indicators were kept with all their joints in working order, he thought the I.H.P. was well within ½ per cent. of what it ought to be, so that it really was a guide as to what the engine was doing. Regarding the instruments, he had found that on moving a Weston between two machines or near two machines the readings altered. There they found that the Siemens dynamometer was not a really reliable calibrating instrument. He should like to know if the arrangement of water-resistance mentioned by Mr. Morcom kept the load perfectly steady. In the works of which he had experience, they found water-resistance did not keep the load as steady as their ordinary resistance. They had coils of wire, and also ordinary galvanised lattice-wire, which they found a very good steady resistance. With regard to superheat in engines, they had found the engines did not require to be designed for superheat at all. They put superheat on their standard type of engines, and they had never had any difficulty through wear or any other cause, and, when they went back to the saturated steam, they did not find any reduction in the steam consumption. What did Mr. Morcom mean by the superheat of these light loads? He should like to know where the superheat was measured. Mr. Reynolds

Mr. MORCOM said they took the temperature of the steam-pressure gauge. Mr. Morcom.

Mr. REYNOLDS said they had found no extra lubrication was required with superheat. That very afternoon he was running an engine at about 200° superheat, and somebody suddenly discovered that the side-feed lubricator had not been working for a couple of hours, but the engine had not seized up. They had found a very similar curve to that shown by Mr. Morcom in their trials at Rugby. It would be interesting to see what the quarter-load curve would be like on the line shown. Did it come and meet the full-load curve like the half-load Mr. Reynolds.

Mr. Reynolds. line seemed to do? They had found with the full, ¾, ½ and ¼ loads that, as the superheat went up, the consumption tended to become the same at each. In fact, with a fairly high degree of superheat, they had found the water per indicated horse-power to be the same quarter-load right away down below, giving very much the same effect as a variable cut-off would.

Mr. Walsh. Mr. J. M. WALSH endorsed what had been said as to the difficulty experienced at Messrs. Belliss and Morcom's works with the Platinum Wire Pyrometer, and said it was pretty obvious that the wires were broken by the rush of steam. They put a perforated plate round the arrangement that carried the wires, but it did not seem to help matters much. They might have succeeded better with one or two very small holes, but he thought the instrument would not give altogether a correct reading if the wires were shrouded from the outer temperature. After all, the reading was not taken directly, but by measuring the varying resistance of the wire on the Wheatstone bridge. His experience with the Wheastone bridge was that it could vary a good deal if you got any error in your leads running from the pyrometer to the measuring box, and the Wheatstone bridge. As had been emphasised, an inspector must take the instruments for granted. There was always this about the Weston ammeters, they could be calibrated from an independent source, they were generally supplied sealed up with their shunts, and, if there was any question at all about the ammeter readings, the instruments could be taken away and calibrated by the Board of Trade. They had had results of tests at Messrs. Belliss and Morcom's corrected by the calibration of the Board of Trade. Then the weighing tanks might be inaccurate, but they were very easily checked by standard weights. They had a series of standard weights, so that inspectors who chose to do so might check the arrangement at the beginning and at the end of the run. Of course, the indicator could be made to read almost anything, and might give a very thick line, but that was one of the points where the expert came in—he sharpened his pencil. You could get a line very much narrower than the hundredth part of an inch. If you took a series of tests under exactly the same conditions of engine running, the inaccuracy could be limited. He was present at the test mentioned in the paper, regarding the effect of forced lubrication; the results mentioned represented the average obtained for a dozen sets of cards, and they did not vary except in the third decimal place.

Mr. Ashlin. Mr. F. J. W. ASHLIN said his experience had been that it was very difficult to get two ammeters even of the Weston type, and irrespective of size, to read alike, though they might be on the same circuit with the same current passing through. He should like to ask whether Mr. Morcom found the shunts themselves varied in actual use. They knew alloys crystallised at a certain temperature, and he knew himself that the alloys of which the shunts were made varied very much, and it was a question whether they should not come back to the fairly frequent recalibrating of those instruments to get anything like a standard reading at all. If they worked water consumption out to decimal point, they needed to be equally careful not only in their steam readings, but also in their electrical readings. He should like further particulars

than those given in the paper as to the actual net gain due to superheat under different conditions. Mr. Ashlin.

Mr. MORCOM, replying, passed over such remarks by Mr. Henry Lea as had already been answered. With regard to the duration of tests, he said his point was that it was unnecessary to waste the time of the staff in lengthy measurements of water consumption. When he said the indicator was used to compare B.H.P. with E.H.P. he meant B.H.P. and not I.H.P. They ran the engine on the dynamo and the efficiency came out low, and, however accurately they might indicate, they could not find anything wrong with the indicators. They then took the generator off, put it on the brake, ran with the indicator again, and took the brake efficiency, and in that way they found the actual efficiency of the generator. He was afraid he was too hard on the assistants sent down by consulting engineers, for he must confess some of the trouble with the potentiometer was due to the works assistants. The tank 4 feet wide by 10 feet long and 4 feet deep ran at 500 volts and with 2,000 amperes with a steady flow of canal water which had a very high conductivity. Mr. Morcom.

Mr. HENRY LEA: If you were to run town's water through that tank you would have to acidulate it? Mr. Lea.

Mr. MORCOM assented. With regard to the gain due to superheat, he did not think that the excessive gains over the early ranges which were mentioned would be found with engines having carefully designed piston and valve rings which were of such a nature as to fulfil an Admiralty trial for steam tightness. Referring to instruments, they found the Weston ammeters were not only very convenient in having a nice wide scale and a good big range, but they also found them extremely accurate, and they kept so. They had their own ammeters constantly calibrated, but there was never anything to be put right. He did not think their seals had been broken for a considerable time past. The hot-wire ammeters they used were Johnson and Phillip's. The "Solenoid" type of instrument was the Kelvin ammeter. One of the speakers had said that in the test-house with which he was connected, they had fixed instruments with permanent connections. They had the same arrangement at Belliss and Morcom's works once, but they gave it up because they found it so much more convenient to have the instruments reasonably close up to the engines under test. Their test bed was a very extended one, and, unless they accumulated instrument boards all over the place, which would take up all the available space, they would have to take a long walk to read the instruments. As to loss of vacuum, no doubt they did lose a certain amount, but they did not need to make any allowance for it, as they obtained their guaranteed figures without it. The Siemens dynamometer which they used was a large one enclosed in glass, and its readings had shown great accuracy, well within 1 per cent. over a long period. He had no doubt it was the case that certain engines required no additional clearances for superheat as had been suggested. In some, cylinder lubrication might be unnecessary because of the amount of oil which came up from the crank chamber. He could not say he should think much of a figure for water consumption per I.H.P. at quarter-load, Mr. Morcom.

Mr. Morcom.

because the efficiencies at quarter-load were generally fairly low, but it was evident that if the curves did fall at quarter-load and other loads gained proportionately by superheat, they would come closer together as the temperature went up, because the proportionate gain on a larger figure made a bigger absolute difference. He had no further figures on the point. The figure he had given as to fuel gain was taken fairly recently on a trial, and they had had a check on it which bore out the estimate of 25 per cent. However, as they had to test at the rate of about an engine and a half a day, they had not much time for fuel trials.

MANCHESTER LOCAL SECTION.

MERSEY RAILWAY.—MULTIPLE CONTROL.

By H. L. KIRKER.

(Abstract of a Paper read at Meeting of Section, March 1st, 1904.)

SYNOPSIS.

1. Dates.
2. Reasons for Electrifying.
3. Execution of the Contract.
4. Brief Description of Present System.
   (1) Main tunnel, (2) drainage, (3) ventilation, (4) lifts, (5) permanent way, (6) rolling stock, (7) fire-proofing, (8) power station, (9) cables, (10) signal cabins, (11) lighting, (12) air compressors.
5. Features Conducive to Economy.
   (1) Ventilation plant, (2) coal-handling machinery, (3) feed water system, (4) storage battery, (5) multiple control.
6. Results.
7. Bibliography.

DATES.—The Mersey Railway Company was formed by Act of Parliament in the year 1866, the experimental heading begun in 1879, the permanent work started in 1881, and the road opened for traffic on the 20th of June, 1886. The contract with the British Westinghouse Electric and Manufacturing Company, Limited, for the complete electrification of the road was signed the 15th of July, 1901, and electric traction was inaugurated the 3rd of May, 1903.

REASONS FOR ELECTRIFYING.—Thirty-two million passengers crossed the Mersey River in 1901. Of this number less than 30 per cent. (9,000,000) took the smoky tunnel of the Mersey Railway. The operating expenses for several previous years had been about 90 per cent. of the gross receipts. Electric traction had been proposed at frequent intervals during the history of the road, and was finally adopted in 1901. The Mersey management were convinced that electric traction would solve the smoke problem and reduce the operating expenses. They believed also that a frequent, rapid, and clean service would not only divert more of the traffic to the tunnel, but increase the total volume of business by rendering the Wirral Peninsula easily accessible from Liverpool. The British Westinghouse Company examined the situation, offered to take the complete contract for the electrification of the road without interruption to steam traffic during the construction period, and to give certain guarantees as to the operating expenses. The contract was accordingly let to the Westinghouse Company, and the work of electrification immediately begun.

EXECUTION OF THE CONTRACT.—Twenty-two months from the letting of the contract electric traction was in full swing.

During these 22 months a complete 5,000 H.P. station was erected

on the old fan-house site near Hamilton Square Station, Birkenhead, 8,000 special sleepers put in the permanent way, 1,800 tons of collector rail laid and bonded, the necessary power and lighting cables installed, new rolling stock produced, and the railway employés trained for electric operation.

Ninety days elapsed from start to finish of the 250 ft. stack containing 865,000 bricks, the actual number of working days being 56. The work on the permanent way in the tunnel was of such a disagreeable nature that difficulty was experienced in retaining the men. The actual working hours were from 12.30 a.m. till 4.30 a.m., except on Sundays when they were extended to noon. The air was never free from smoke. As the greater part of the cable work was in the ventilation headings, there was here, in addition to the smoke, a seventeen years' accumulation of soot to contend with.

The aim was to open early in 1903. While this was not entirely realised, the work had so far advanced by the 14th of February that a five-car train was run between Birkenhead Park and Central Station (Low Level), Liverpool. The work of training the drivers was then immediately begun. A schooling train, under the direct supervision of a Westinghouse expert and the Resident Engineer of the Mersey Railway, was put on the Park Branch, and the drilling was done between the hours of 1 a.m. and 4 a.m.

After the drivers had gained a certain amount of experience, two electric trains were run in between the regular steam trains during traffic hours, but no passengers were carried on them.

The Board of Trade inspection took place the first week in April; the approval followed shortly after.

Two methods of inaugurating electric traction were considered:—

(1) A gradual change.
(2) An instantaneous change.

The arguments in favour of the gradual substitution were that it was a natural method for the power-house staff, the train crews, the signal cabin men, and the traffic department in general, to acquire easily a familiarity with the new system; that the various mishaps incident to the commencement of electric traction would cause the least delay to traffic during the period of mixed service, and, lastly, that this method would avoid the nervousness on the part of the employés incident to an instantaneous change from steam to electricity. However, as the prejudice against smoke was so strong, it was decided that electric traction ought to begin in a pure atmosphere in a clean and bright tunnel, and arrangements were made for an instantaneous and complete transformation. Accordingly, the training cars were continued and an increasing number of electric trains run during non-traffic hours for the general education of the whole staff. The steam traffic was to cease with a certain day, and electric traction, with a complete train service, to begin on the succeeding morning.

On the night of the 25th and 26th of April, 1903, a trial run of the complete service of nine trains on a three-minute schedule was made for Messrs. Kennedy and Jenkin, the technical advisers of the Mersey

Railway Company. After this test an immediate opening was decided upon. Accordingly, on the night of the 2nd of May, all the steam stock was rolled away. During the forenoon of the 3rd (Sunday) the plant was operated for an inspection by the Mersey and Westinghouse officials, representatives of the various sub-contractors, and members of the Press. After this inspection the service was thrown open to the public, and electric traction with a three-minute schedule inaugurated.

This is the first example of an instantaneous change from steam operation to electric on a railway system.

The three-minute schedule thus inaugurated has been successfully maintained. This, in the light of the facts that 250 men are more or less directly concerned in the operation of these trains, that 90 per cent. of these men are old steam employés, that these trains are operated in a tunnel, and that 750 trains per day pass through Hamilton Square Station, speaks well for the simplicity of electric traction and the adaptability of the men that have come in contact with it.

BRIEF DESCRIPTION OF THE PRESENT SYSTEM.—There is little to add to what has already appeared describing the present system, so this section is mainly intended for reference, although some of the illustrations are new.

(a) *Màin Tunnel.*—The Mersey River Tunnel extends from Central Station, Liverpool, to Central Station, Birkenhead, a distance of 2·1 miles. From Birkenhead Central Station to Green Lane there is an additional length of tunnel of 0·24 mile, and from Hamilton Square Station to Birkenhead Park a branch tunnel of 1 mile. The tunnel is 26 ft. wide and 19 ft. high from the rails.

(b) *Drainage.*—There are two pumping stations, one on each bank of the river. Together they handle 6,000 gallons of water per minute. They are equipped with a total number of six pumps, and have a maximum capacity of 18,000 gallons per minute, so that the possibility of flooding the tracks is extremely remote. In fact, the structure of the tunnel and the effectiveness of the drainage system are such that a sprinkling car is used occasionally to lay the dust. No change has been made in the pumping arrangements, but since the engines operate at 60 lbs. pressure and the Birkenhead pumping station is supplied from the power-station, it has been necessary to arrange the steam piping so that any one of three of the power-station boilers can be worked at 60 lbs. for this pumping plant.

(c) *Ventilation.*—The ventilation of the tunnel is now entirely satisfactory. The steam plants have been suppressed, and two 12 ft. and one 5 ft. motor-driven fans installed. The 5 ft. fan is at Low Level Station, and the other two at James Street and Hamilton Square Stations. In normal operation each 12 ft. fan moves 65,000 cubic feet of air per minute, with a consumption of 24 H.P. The natural ventilation of the tunnel, however, is such that the 5 ft. fan is seldom required, the greater part of the work being done by one 12 ft. fan.

(d) *Lifts.*—The steam-driven lift pumps have been replaced by motor-driven ones, and at the same time the speed of the James Street lifts has been increased 60 per cent. The pump motors are automatically started and stopped by variations in the water pressure.

(e) *Permanent Way.*—The distance from Central Station, Liverpool, to Rock Ferry Station (two terminals) is 3·75 miles, and from Hamilton Square Junction to Birkenhead Park Station (the other terminal), a distance of 1·2 miles. The track is double throughout, and has a total length, including sidings, of 12·25 miles. The repairing and cleaning sheds are at Birkenhead Central Station.

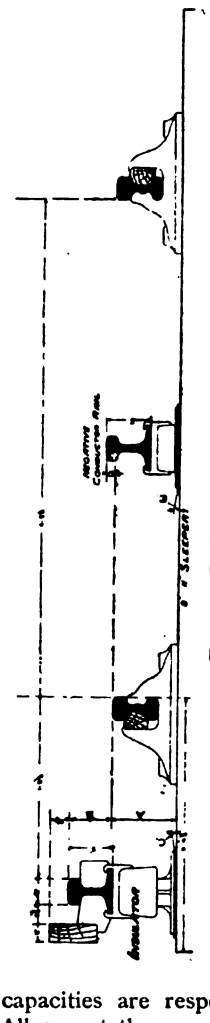


Fig. 1.—Position of Collector Rails.

The collector rails, both positive and negative, are insulated and the positive is provided with a guard timber. The negative 'bus-bar on the main station board is earthed on the running rails at the point nearest the power-station. This practically reduces the negative rails to the same potential as the earth, and consequently eliminates them as a source of danger from shock.

Fig. 1 shows the relative positions of running rails, collector rails, and guard timber. The positive collector rail is outside and above the running rail. The negative is also slightly higher than the running rails, and is between them. Both are insulated on glazed earthenware blocks. The insulators are mounted on every third sleeper, which are 3 in. longer than the others.

Fig. 2 shows the method of mounting, insulating, and bonding the positive collector rail, and frequent tests have shown the insulation to be entirely satisfactory.

The conductivity of the collector rails is one-seventh that of copper.

(f) *Rolling Stock.*—The rolling-stock is entirely new. It consists of 57 cars, of which 24 are motor cars, and 33 trailers, sufficient for 11 five-car trains and two spare motor cars. The trains are operated on a three-minute schedule, which calls for nine trains in service and two standing by. The new cars are of corridor type, and measure 60 ft. over all. There are several kinds—first-class motor, third-class motor, first-class trailer, third-class trailer, and composite trailer. Their seating capacities are respectively 48, 50, 60, 64, and 62 passengers each. All except the composite trailer are provided with smoking compartments. The second class was abolished with steam traffic.

The trains vary in size from two to five cars. In the three, four, and five-car trains there are two motor cars, which are situated at the extremities. It was intended to run a three-minute schedule for rush hours only, but the Railway Company decided to maintain it during the whole traffic period. Accordingly Mr. J. Shaw, Resident Engineer of

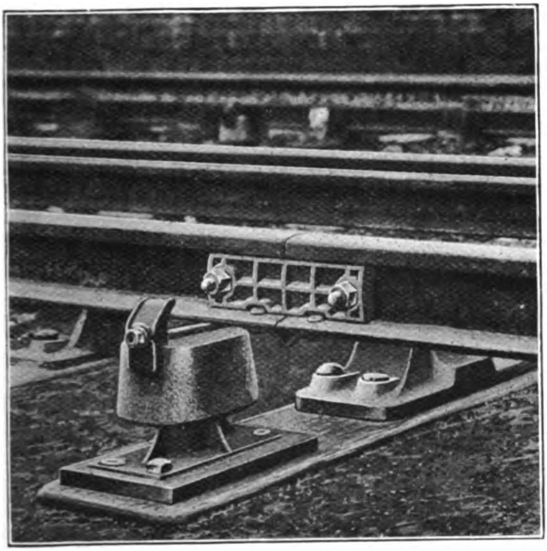


FIG. 2.—Insulation and Bonding of Collector Rails.

the Mersey Railway Company, secured the necessary Board of Trade permission to add controlling gear to the trailer platforms. This arrangement has advantages in the case of the Mersey Railway. The three-minute schedule required 18 motor cars out of 24, and trailer cars according to the traffic. As traffic has two decided peaks per day, there is a considerable amount of building up and cutting down of trains. Consequently the ability to uncouple a four-car train in the middle, and make two two-car trains of it during light traffic, admits of the three-minute schedule with fewer cars, diminishes the wear on the rolling stock, and increases the time available for inspection.

Each car is provided with two Baldwin four-wheel bogie trucks, standard Westinghouse air brake, with storage reservoirs, Janney couplers and buffers, pantograph gates, etc. Each motor car is equipped with four Westinghouse 100 H.P., 600 volt railway motors, one main controller, starting rheostat, etc., and electro-pneumatic control.

The corridor principle is carried through the luggage and driving compartments to the end of the train. This is a valuable feature on occasions demanding the transfer of passengers from one train to another on the same track. Moreover, as the cars are provided with platforms, passengers can also be transferred in case of emergency to a train on the neighbouring track.

(g) *Fireproofing.*—The driver's compartment is lined with $\frac{3}{16}$ in. asbestos slate. All cables have non-combustible insulation; the motor leads are carried in iron tubing; the car bottom directly over the motors, rheostats, and cables is lined with the same asbestos slate. In addition to the circuit-breaker in the driver's compartment, there is a fuse on each shoe beam. The power cables are confined exclusively to the motor cars. The control line for the electro-pneumatic control circuits connecting the front and rear motor cars is independent of the power circuit, and gets its current from a 14 volt storage battery. All trains are provided with fire extinguishers.

It should be borne in mind in this connection that the size of the tunnel, its natural ventilation, the independent lighting, the grounded negative rail, and the system of train despatching, enable passengers, in case of necessity, to get out of a train and proceed on foot to the nearest passenger station.

(h) *Power Station.*—The power-station is located near the Junction, and is consequently at the centre of the system.

The building is of brick and steel construction, 135 ft. by 144 ft. 7 in., divided by a wall into boiler and engine rooms. There are nine Stirling water-tube boilers of 4,370 square feet of heating surface, built for 170 lbs. steam pressure, provided with superheaters, and of a nominal 550 H.P. rating. The furnaces have each 115 square feet of grate surface, and are provided with Roney stokers.

The draft is controlled by dampers worked by an automatic regulator; the action of the regulator depending upon the variations of the steam pressure.

There are two surface condensers, each capable of handling 70,000 lbs. of steam per hour, and each provided with circulating and dry vacuum pumps.

A pump discharges the water of condensation into the jet heater. Between the jet heater and the hot-well there is a Harris Purifier and filter capable of treating 100,000 lbs. of water per hour by a combined chemical and physical process. There is also a softener for treating the make-up water.

From the hot-well the feed water is forced through the economisers by one of two Weir compound feed pumps. The economisers consist of 940 9-ft. tubes.

The coal is dumped directly into the crusher pit either from wagons on the siding or from carts in Canning Street. From here it is carried by the conveyor to the boiler-room bin. The conveyor can handle 30 tons per hour, and the bin has a storage capacity of 600 tons. There are weighing machines in the chutes between the bin and the hoppers. The same conveyor deposits the ashes in another bin directly over the railway siding.

The steam piping is steel, and all pipes of 6 in. diameter and over have welded flanges. The main header (10 in. and 12 in.) is arranged in ring and provided with sectioning valves. Between each boiler and the ring there is a ball-isolating valve, a stop valve, and an additional valve between the superheater and the steam dome. All the high-pressure piping is lagged. The exhaust main is of rivetted sheet steel pipe. The exhaust valve of each engine is bye-passed by an automatic valve, and in the main exhaust there is a 42 in. automatic atmospheric relief.

The engine-room contains three 1,200 k.w. and two 200 k.w. generating sets, one reversible booster, and a 19-panel board for controlling the electrical apparatus. All the steam and electrical machinery is of Westinghouse manufacture. The 1,200 k.w. engines are vertical cross compound 30 in. and 60 in. by 48 in., 94 r.p.m., built to carry 60 per cent. overload at 160 lbs. pressure, 100°F. superheat and 27 in. of vacuum, and an overload of 40 per cent. when running non-condensing.

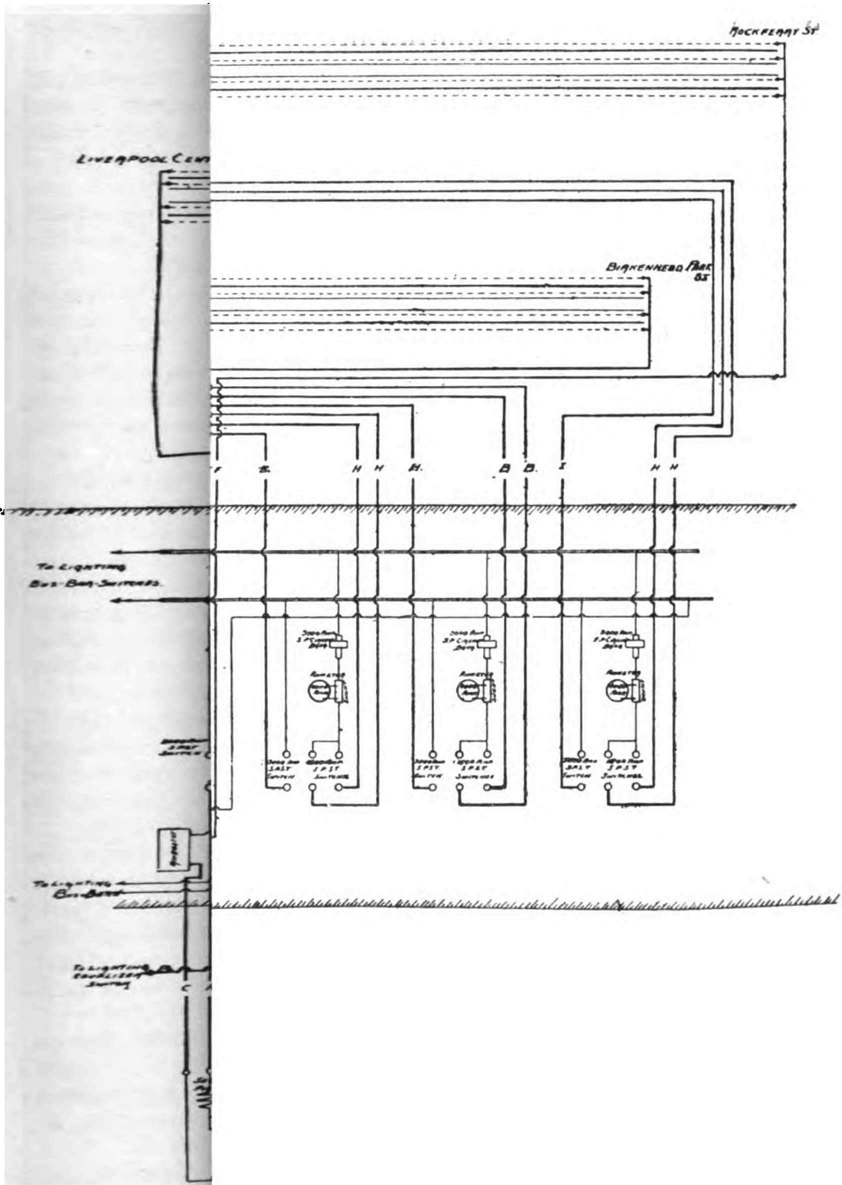
The main engines are provided with butterfly emergency and high-pressure poppet valves. The low-pressure valves are of the Corliss type. There are two governor belts, and the gear controls both high- and low-pressure admission. A central gravity system of lubrication is used.

The dynamos are compound wound, 650 volt, direct current. They are also provided with collector rings, and can supply 25 cycle three-phase alternating current. This alternating-current provision is to take care of the long-distance transmission that will be necessary for future extensions.

The 200 k.w. engines are 16 in. and 27 in. by 16 in., 250 r.p.m., and each is direct-connected to a compound-wound, 650 volt dynamo.

The booster group consists of a 2,000 ampere reversible shunt booster, a compound-wound exciter, and a 150 H.P. compound-wound driving motor. The booster armature is in series with a battery of 320 type-R Chloride cells having 1,000 ampere-hours capacity at one hour rating, and capable of giving 2,000 amperes momentary discharge.

Figure 3 is a diagram of the main switchboard circuits. The battery (with its booster) operates in parallel with the main generators.


ROCKFERRY ST.
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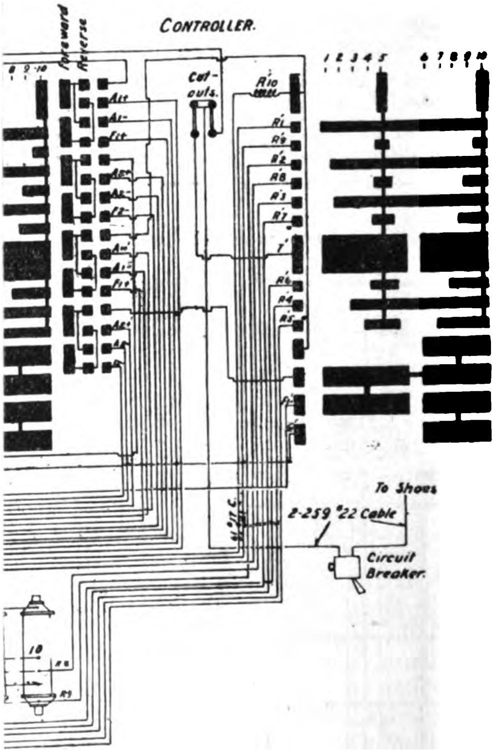

CONTROLLER.
Foreward
Reverse
Cut-outs.
To Shoes
2-259 #22 Cable
Circuit Breaker.

The 200 k.w. units are used for lighting, and are independent of the main circuits, although they can be thrown into parallel with them, if required.

(i) *Cables.*—Paper-insulated lead-covered cables are used almost exclusively. However, in the case of track cross-bonds, rubber-insulated lead-covered cables are used to avoid sealed end-connections. All these cables are of the British Insulated and Helsby Cables Company's make. The cables reach the main tunnel through the ventilation headings. In the ventilation headings, and generally in the main tunnel, they are supported on iron brackets. Along platforms and retaining walls they are supported in boxes, and where they pass underground they are laid on the solid system. The lead sheathings are bonded together and earthed at the power-station and at the track as well. Frequent examinations have detected no trace of electrolysis.

The power circuits to the track consist of eleven cables of 1·25 square inch cross section, all of which are connected to the collector rails within the immediate vicinity of Hamilton Square Station.

The two positive Liverpool cables are controlled by independent switches and a common circuit-breaker. One of these cables is for the up track and the other for the down. The two negative cables are connected to a single switch on another panel. The Rock Ferry branch is controlled in the same way, likewise the Birkenhead Park branch, except that here there is but one negative cable.

(j) *Signal Cabins.*—At each signal cabin there is a break in the positive collector rail, and the circuits pass through switches and circuit-breakers in the cabin. All cabins of any one branch are, therefore, in series.

(k) *Lighting.*—An independent twin lighting cable is carried to the extremity of each branch of the road. During traffic hours the lighting current is supplied by one of the 200 k.w. generators. During non-traffic hours, when all the engines are shut down, the current comes from the storage battery. 1,440 incandescent and 109 arc lamps are used. The incandescents are run three in series, and the arcs from ten to thirteen in series. The arcs are of the Westinghouse Bremer type. The arc and incandescent circuits are controlled from small tablet boards in the various stations. The wiring from these boards is carried in enamelled steel tubes of the water-tight screwed-joint type. The tunnel lights are placed 100 feet apart on either side of the tunnel, and are controlled from the signal cabins.

(l) *Air Compressors.*—The compressed air for the brakes and pneumatic control system is supplied from compressor stations at Rock Ferry and Birkenhead Park. Each of these is provided with two 15 H.P. motor-driven, automatically-controlled compressors that keep the station storage reservoirs charged up to 150 lbs.

There are also two compressors at Birkenhead Central and one at Low Level. The storage reservoirs on the motor-cars have a capacity sufficient for two return trips. They are charged to 135 lbs. This pressure is reduced to 90 for braking and 40 for control.

Features Conducive to Economy.—Electric traction is the

natural solution for short hauls and dense traffic. The strong points of the system are cheap power and efficient application. In the case of the Mersey Railway, the coal-handling arrangements, the feed-water system, and the storage battery are important elements in the production of cheap power. The efficient application of this power is secured (1) by the location of the power-house at a point where the losses in conductors and the investment in cables are a minimum, and (2) by the use of multiple-unit train control, which prevents extravagance in the use of power.

(I.) *Ventilation.*—The elimination of the locomotive solved the smoke problem and reduced the ventilation charges more than 80 per cent.

(II.) *Coal-Handling Machinery.*—The mechanical conveyor and stoker handle 480 tons of coal per week. The time of eleven men is charged against this work. The operation and maintenance charges, including the ash-handling, do not exceed £20 per week. It is estimated that if the mechanical work were done by hand, twenty men would be required, and the corresponding charges would be £39, a little less than double the present cost. The present cost of coal-handling is 10d. per ton. This covers dumping, conveying, stoking, removing of ashes, together with the necessary power and the maintenance of the plant.

The effectiveness of the stokers is also attested by the fact that there has not been a single smoke summons since the first few weeks of electric working.

(III.) *Feed-Water System.*—The use of a surface condenser and a feed-water purifier enables the condensed steam to be returned to the boilers. The average electric load on the station is 22,000 k.w.-h. per day. At 23 lbs. of water per kilowatt-hour this means 506,000 lbs., or 50,600 gallons per day. Now, since the auxiliaries exhaust into the jet heater, and the condensation in the 160 lbs. steam lines is returned to the boilers, the assumption can be made that about 9 per cent. or 4,600 gallons of make-up water is used per day. The cost of purifying is taken at 1d. per 1,000 gallons, and the cost of city water at 7d. The net result, therefore, is a saving of 46,000 gallons per day at 6d. per 1,000 gallons, which means £420 per year.

The discharge from the neighbouring pump station supplies tunnel water for condensation purposes.

The combined use of the condensation, jet heater, and economiser, effects a saving in fuel. According to readings taken a few days ago, the actual difference in temperature between the make-up water going into the hot-well and the feed-water going into the boilers was 148°F. Now, as indicated above, the average electrical output of the station is 22,000 k.w.-hours per day, which at 23 lbs. of water per k.w.-hour (extending over 24 hours and including all auxiliaries) means 506,000 lbs. of water per day. To this must be added 250,000 lbs. per day for the pumping station, making a total of 756,000 lbs. of water evaporated every 24 hours. Since this water enters the boiler at a temperature 148°F. above the borough supply, it follows that 756,000 lbs. of water have been raised 148°F., which means that

112,000,000 heat units have been added to the feed-water by the condensation, jet heater and economiser. Allowing 12,000 B.T.U. per pound of coal and 65 per cent. for the all-day efficiency of the boilers, then 7,800 heat units of every pound of coal consumed get into the steam through the boiler. It is evident, therefore, that the 112,000,000 units absorbed from the condensation and the gases represent a saving of 14,360 lbs., or 6·4 tons of coal per day. Since the average consumption is 54 tons per day, the saving is practically 11·8 per cent. With coal at 10s. per ton, this means the saving would more than pay for the economiser in one year.

(IV.) *Battery and Booster.*—During the greater part of the day one dynamo and the battery are able to carry the load. The average week-day load is 25,000 k.w.-hours per day, or an average of 1,280 k.w. per hour for the 19½ hours of actual service. This average load exceeds slightly the capacity of one generator. During the ordinary traffic the line load varies rapidly, and may pass from zero to 3,500 amperes in the space of a few seconds. However, the action of the reversible booster is such that the battery discharges into the line during the peaks, and is charged when line load is light. The result is that the load on the engines is fairly uniform, and is slightly less than full load. This, of course, is an economical running condition. During the heavy traffic the line load ranges from zero to 5,000 amperes. A second generator is used during these periods. The action of the booster is such as to keep both machines working fairly uniformly at about two-thirds of their capacity. (In addition to the charging the batteries get when the two main generators are running, they are completely charged once a week after traffic hours.)

(V.) *Multiple Control.*—The above-mentioned features are common to many power-stations, and are, consequently, from an engineering standpoint, secondary in interest to the most striking electrical feature of the system, viz., the multiple-unit system of train control.

There has been an evolution in the method of electrically propelling heavy trains. The process has distributed the motors among several cars of the train, and narrowed down the use of electric locomotives to special cases. The advantages resulting from the distributed application of the motors are, of course, smaller motors, more available adhesion, greater acceleration, increased flexibility in the make-up of trains.

There has also been an evolution in the control mechanism used with the distributed motors. The heavy controllers at the ends of the train, that handled singly the total current of the train, have been divided up into a number of smaller controllers, put on several motor cars, and linked together by an auxiliary control system. There are several distinct types of auxiliary control, but the fundamental idea is the same in each, *i.e.*, independent motor-car units and centralised control.

In one of these the controller on each motor car is operated by air pistons. The air supply comes from a storage reservoir common to the brakes and auxiliary control, and the air valves are worked by electro-magnets that get their current from 14-volt storage batteries.

The multiple-control switches or master controllers are inserted at several points in a 7-core cable extending the full length of the train, and any one of these switches can make the various connections between the battery and magnet valve necessary for the operation of the control. In this system the auxiliary control is entirely independent of the main power circuit.

Mersey Control.—On the Mersey Railway the electro-pneumatic drum-type controller is used, as it is especially suited to the conditions. For, while the service is severe, due to steep grades, high average speed, and heavy trains (a loaded five-car train weighs 135 tons), the maximum current taken by any one motor car does not exceed the capacity of a drum type of controller that can be easily installed in the driver's compartment—a location convenient for inspection. Air brakes being used, the storage reservoir for the brakes furnishes the necessary air supply. A 14-volt storage battery current is used on the auxiliaries, consequently the electro-magnets and multiple-control switches are simple and robust, and the fire hazard is absent from this part of the apparatus. No 'bus lines run through the train, so that the recent Board of Trade ruling on this point for underground trains was anticipated.

Four-Car Train.—A four-car train will serve the purpose of illustration. It has a motor car at each end, and at one end of each motor car are the luggage and driving compartments. Each motor car is equipped with four motors, six collector shoes, a starting rheostat, main controller, the necessary cables, two small storage batteries, two multiple-control switches (one at each end of the car), the necessary brake apparatus and accessories incident to the electro-pneumatic control. The power cables do not extend beyond the motor car, though the 14-volt control cable extends the whole length of the train.

The two trailer platforms at the middle of the train are each provided with a multiple-control switch and a driver's brake valve, thus making six points on the four-car train, from any one of which the driver can operate simultaneously both main controllers. As the train runs shuttle fashion, the driver changes ends at the terminal stations; and when a four-car train is cut in two it is driven alternately from the driver's compartment and the rear trailer platform. If motor cars are run singly they are driven alternately from the driver's compartment and the rear platform. There is but one multiple-control switch-handle per train, the driver carries this handle with him when he changes compartments. With the handle removed the switch is always in zero position.

Fig. 4, a motor-car wiring diagram, indicates the relative position of the collector shoes, fuses, automatic circuit-breaker, starting-rheostat, controller, and motors. The two motors on the forward truck constitute a group independent of the two on the rear truck. The series-parallel working is confined to the two motors of each group, and each pair has its own drum and isolating switch in the main controller. A common reversing switch is used for all four motors.

Fig. 5 shows the operating head of main controller.

Fig. 6 is a complete diagram of the auxiliary circuits, and shows also the air piping, valves, and cylinders. Details of this diagram

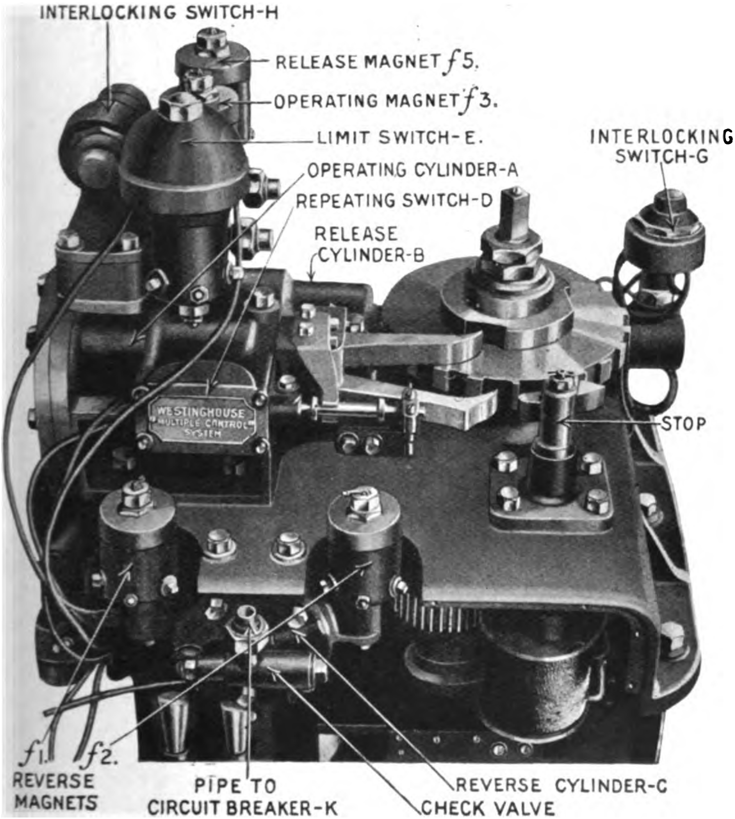


FIG. 5.—Operating Head of Main Controller.

show how the drums are thrown "ON" or "OFF," the reverser set, and the circuit-breaker tripped and closed.

Operating Cylinder.—Fig. 6 shows the ratchet plates on the common shaft to which the two main drums are geared. Fig. 5 shows the ratchet plates, pawls, and operating cylinder. The admission of air pressure into this cylinder ratchets up the controller.

Release Cylinder.—Fig. 5 and 6 also show the release cylinder. Its piston rod is provided with a rack that engages a pinion on the shaft below the ratchet plates. The admission of air pressure into this cylinder throws off the controller, the operation being practically instantaneous.

Reverse Cylinder.—Fig. 6 shows diagrammatically the two reverse cylinders. Their common piston-rod is provided with a rack that engages a pinion on the reversing drum spindle. The admission of air pressure into one of these cylinder throws the reverser. However, as the reverser is not intended to break current, it is interlocked in such a way that it can be thrown only when the main controller is "OFF." The same figure shows the interlocking switch "G" in the reverse cylinder magnet-valve circuit. The first movement of the controller towards "ON" frees the switch and allows the spring to open it. Further action of the reverser is impossible until the controller is "OFF" again.

Safety Switch.—The function of the safety switch "H" is to prevent the possibility of the operating and release cylinders trying to work at the same time. As this switch is in series in the operating cylinder magnet valve circuit, it is evident that the air pressure which throws off the controller also breaks the valve circuit.

Repeating Switch.—The forward motion of the operating piston breaks the operating cylinder magnet valve circuit. This relieves the air pressure in the cylinder, then the spring returns the piston, this closes the circuit again, another stroke follows with the same result, and so on until the repeating switch is shunted or the circuit broken at another point.

Limit Switch.—The limit switch locks the operating cylinder when the starting current becomes excessive. Its coil is connected in shunt across the field of one motor; accordingly, when the motor current exceeds a certain amount, the drop across the motor fields is sufficient to send a working current through the limit coil, so closing the switch, and thereby shunting the repeating switch. The repeating switch being shunted, the forward motion of the piston does not break the operating cylinder magnet-valve circuit. However, as soon as the motor current falls to the required limit, the switch opens and the repeating switch becomes effective again.

Air Brake Interlock.—The air-brake interlocking switch prevents the power from being thrown on while the brakes are fully set, and also cuts off the power in case the train parts, and applies the brakes. The switch is in series with the release cylinder magnet-valve circuit, and the air supply comes from the brake cylinder. So long as the air pressure in the brake cylinder exceeds a few pounds the controller is locked. It is necessary, of course, to keep the brakes set slightly to

hold a train on a grade, but the valve spring is so adjusted as to permit power being thrown on under such circumstances.

Automatic Circuit Breaker.—Fig. 6 also explains the pneumatic feature of the automatic circuit-breaker. A magnet valve controls the "Trip Cylinder." The admission of air pressure into the cylinder frees the breaker, but the instant the magnet-valve circuit is broken the pressure is lost, and the spring returns the piston and trips the breaker.

The "Set Cylinder" gets its air supply through one or the other of the reverse cylinders. An examination of the piping shows that the breaker and the reverser are so interlocked that the breaker is closed after the reverser is set; also that a double check valve prevents the discharge from one reverse cylinder getting into the other.

The "Interlocking Switch" on the circuit-breaker is an additional safeguard. Its object is to make the throwing "ON" of the controller follow the setting of the reverser and the closing of the breaker. It accomplishes this by keeping the operating cylinder magnet-valve circuit open until the breaker is closed.

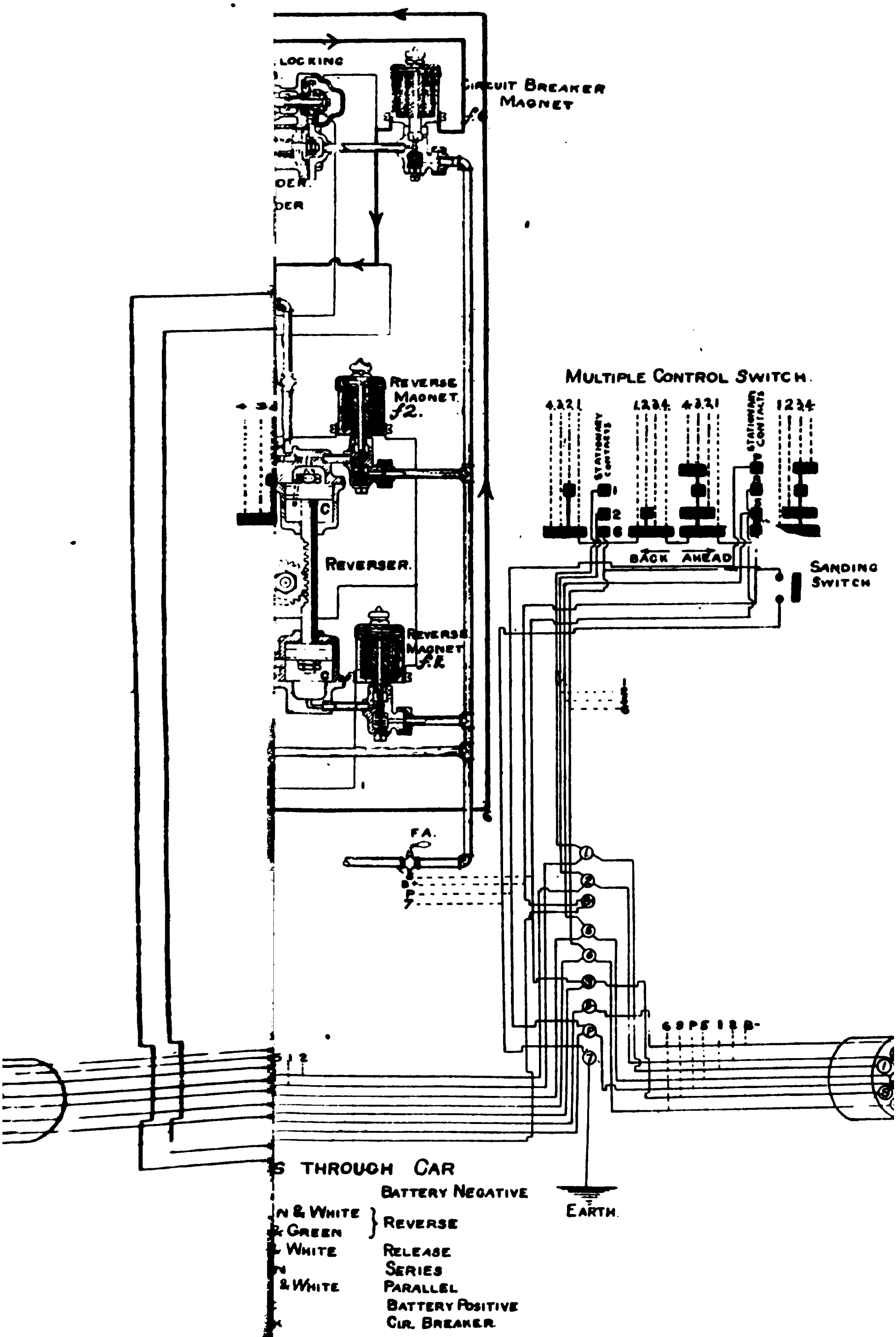
Operation.—The combined action of the above-mentioned apparatus, to produce a forward motion of a train, is as follows :—

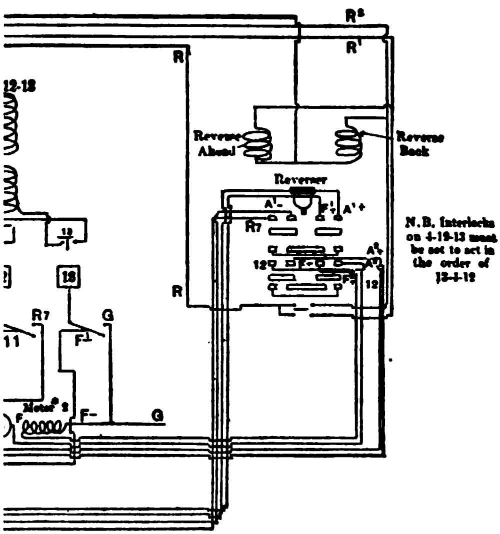
The handle of the multiple-control switch is moved from the zero position to the right. As soon as it reaches *position* 1 the multiple-control switch closes the circuit-breaker trip-cylinder magnet-valve circuit. As pointed out above, this frees the circuit-breaker for closing. See Fig. 6.

As soon as the handle reaches *position* 2, the multiple-control switch closes the forward reverse cylinder magnet-valve circuit. This admits air pressure into this cylinder, and the air in turn throws the reverser for forward motion of the train (in case the reverser is not already in that position). The reverser piston home, the air pressure, as pointed out above, travels on to the circuit-breaker set cylinder, and closes the breaker (in case it is not already closed). The setting of the breaker closes its interlocking switch, and thereby completes the circuit through the release cylinder magnet-valve circuit. The energising of this valve relieves the air pressure in this cylinder, and frees the controller.

As soon as the handle reaches *position* 3 the multiple-control switch breaks the forward reverse cylinder magnet-valve circuit, and allows the set piston of the circuit-breaker to return to its normal position. At the same time the multiple-control switch has closed the operating cylinder magnet-valve circuit, and air pressure is thereby admitted into the operating cylinder; then the piston commences to ratchet up the controller. The time occupied so far is about one second. If the handle is held in position 3, the operating piston moves the controller to full "series" and then stops, for there is an interlocking switch on the rotating part of the main controller that shunts the repeating switch when full series is reached. Had the handle been carried to position 4, the operating cylinder would have continued to work until the full "parallel" position was reached, for there is a similar interlocking switch that shunts the repeating switch at full parallel.

"*Off.*"—To throw the controller "OFF," the handle is returned to


LOCKING
CIRCUIT BREAKER MAGNET
REVERSE MAGNET f2.
REVERSER.
REVERSE MAGNET f.1.
MULTIPLE CONTROL SWITCH.
STATIONARY CONTACTS
BACK
AHEAD
SANDING SWITCH
F.A.
6 S P F 1 2 B-
EARTH.
S THROUGH CAR
BATTERY NEGATIVE
N & WHITE
& GREEN
REVERSE
& WHITE
RELEASE
SERIES
& WHITE
PARALLEL
BATTERY POSITIVE
CIR. BREAKER


R2
R1
R
12-13
Reverse Ahead
Reverse Back
Reverser
A1 -
F1 +
A1 +
R7
A2 +
12
F -
A2 -
F2 +
12
R
13
13
R7
G
11
F1
Motor No. 2
F
F -
G
N.B. Interlocks on 4-19-13 must be set to act in the order of 13-4-12

1)

position 1. This breaks the operating cylinder magnet-valve circuit, then that of the release cylinder. The breaking of the latter, as pointed out above, admits air pressure into the throw-off cylinder, and the controller is instantly returned to its zero position. Had the handle been returned to zero it would have opened the circuit-breaker as well.

To the Rear.—To move the train to the rear the multiple-control switch handle is carried to the left of its zero position. The chain of events is the same as that just cited, except that the rear reverse cylinder works. Position 1 frees the breaker; position 2 throws the reverser, then closes the breaker, then frees the controller; position 3 opens the rear reverse cylinder magnet-valve circuit, and closes the operating cylinder magnet-valve circuit, which sets the operating piston in motion.

Limit Switch and Economy.—On a line where the distances between stations are short, the train intervals brief, the trains heavy, and grades numerous, the starting current can easily become the determining feature of the station load. Rapid acceleration, of course, is indispensable, but without some such restraining device as the limit switch, the starting current can be pushed to such an extreme as to waste power, and subject the motors to damaging overloads.

Summary.—The above statements cover the elements and the operation of the Mersey Railway Control. The main controller and circuit-breaker are standard apparatus that have long since been perfected, so a description of them is unnecessary. The auxiliaries constitute the novelty, and at the same time they represent the final development of one type of control. As it now stands, the Mersey type multiple-unit control is simple, safe, automatic, and complete, and has been summed up as "doing its own thinking."

THE TURRET CONTROL.—Brief reference will here be made to a later system of electro-pneumatic control, a type in which the revolving drum has been replaced by a group of circuit-breaking switches. This latter type, known as the Westinghouse Turret System, is not only adapted to the work done by the electro-pneumatic drum type, but is especially suited, on account of its lightness and compactness, to heavy work—work which would call for a drum controller of such a weight as to prohibit its being mounted on a passenger car. The turret construction is peculiarly adapted to magnetic blow-out, and its arc-breaking capacity is enormous. In a test of this apparatus three 1,500 k.w. rotaries were short-circuited through one of these controllers, and the resulting current of 18,000 amperes was successfully and repeatedly broken by it. It can be mounted either in the driver's compartment or under the car, but its construction well adapts it to the under-car mounting.

The radially grouped current-breaking switches are closed by air pistons working against powerful springs. The cylinders are drilled in the common air reservoir ring casting.

There is the same absence of fire hazard in the auxiliary gear that there is in the Mersey type, as 14-volt storage battery current is used to work the electro-magnets that control the valves. The safety and

interlocking features are retained, and the main circuit-breakers can be thrown from any master controller in the train.

RESULTS.—It is now practically ten months since electric traction was inaugurated (May 3, 1903), consequently sufficient time has elapsed to get a fair idea as to how the results of operation correspond with the original engineering estimates.

First, as to ventilation: under steam conditions the average cost per half-year exceeded £2,400; with electric traction it falls below £200 for a corresponding period, which is well within the estimated figure.

As to the schedule speed, the rate was 15 miles per hour for the steam trains, and electric traction was laid out on the basis of 20 miles per hour, which is attained.

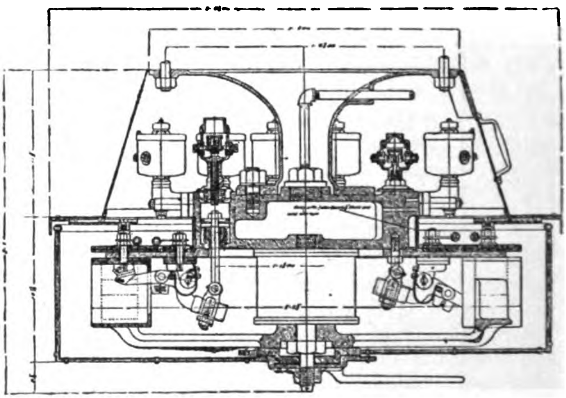


FIG. 7.—Cross Section through Turret.

With the steam locomotives the train mileage was less than 6,000 per week. During the last quarter of 1903 the electric trains lacked but 40 miles to complete an average of 15,000 miles per week. At this rate the total mileage for the year will considerably exceed the original estimate.

Concerning the coal consumption, it was estimated that the average would not exceed 4 lbs. per k.w.-hour at the switchboard. The average for the last quarter of 1903 and the first six weeks of this year is under 4 lbs.

The consumption of energy for a loaded three-car train was estimated not to exceed 9·25 k.w.-hours per train-mile. For the last quarter of 1903 the actual figure was less than nine.

As regards the cost of operation per train-mile, it was estimated that the power-house expenses, the cost of power for operating and lighting trains, and the maintenance of electrical equipments, cars, and collector rails would not exceed 6·75d. per train-mile (for average train 230 ft. long and weighing 105 tons, including motors). The figure for the last quarter of 1903 falls below this estimate. The corresponding cost per

steam train 200 ft. long and weighing 77 tons, exclusive of locomotive, but working at a schedule speed of 15 miles per hour instead of 20, exceeded 11d. per train-mile. It took an 80-ton locomotive to haul the 77-ton steam train.

The total power-station cost, made up of maintenance and operation (coal, water, oil, waste, sundries' labour), did not exceed ·35d. per k.w.-hour during the last quarter of 1903—coal being priced at 10s. per ton, and water at 6d. per 1,000 gallons.

From this it is evident that the results of operation practically agree with the original engineering estimates.

BIBLIOGRAPHY.

A List of Articles bearing on the Mersey Railway.

Engineering, November 2, 1883; April 24, 1903.

Proceedings of the Institution of Civil Engineers—Fox "On the Mersey Railway," and Rich "On Mersey Railway Lifts," May, 1886.

Light Railway and Tramway Journal, April 3, 1903.

Street Railway Journal, April 4, 1903.

Tramway and Railway World, April 9, 1903, and October 9, 1903.

Electrician, May 8, 15, and 22, 1903.

Electrical Review, May 22, 1903.

Westinghouse Companies' Publishing Department—"The Mersey Railway of To-day," May, 1903.

Fielden's Magazine, June, 1903.

LEEDS LOCAL SECTION.

DESCRIPTION OF THE ELECTRICAL EQUIPMENT OF AN ENGINE WORKS AND SHIPYARD, WITH NOTES THEREON.

By H. O. WRAITH, Associate Member.

(*Paper read at Meeting of Section, March* 10, 1904.)

The author proposes to-night to deal, as far as in his power lies and in the short time at disposal, with the question of converting large works of the shipbuilding, engineering, or ironworks type, to electric driving, and where, as a rule, outlay is a very great consideration, and the ruling question rather is "How can I get a maximum saving or profit in pounds, shillings, and pence, for a minimum of outlay?" rather than "What is the most perfect method and apparatus to perform the work I have to do?" Corporations, as an example, and other bodies who can get the command of large sums of capital without trouble, do not hesitate to any great extent, and rightly so, to lay out capital in the most complete and, one might almost say, lavish electrical installations, so as to obtain the utmost maximum of efficiency in working; in some cases, indeed, the refinements of efficiency do not justify the outlay of capital. However, if people did not spend money in what are really experiments, we should not be as wise as we are.

But the class of place the author rather has in his mind to-night is very different. There, an enterprising member of a contracting firm goes to the Executive of the ironworks, or whatever the case in point may be, and, after due preliminaries, says: "Look here, we will convert your works to electric driving for £20,000, and your saving will be £3,000 a year." The Executive says: "That's an awful lot of money to spend; we haven't got and can't raise so much. Besides, I don't know anything about this electricity, and I must be certain that your figures are correct."

After a year or two the Executive decides to convert a portion of the works to electric driving as an experiment, spends £4,000 on it, is pleased with the results if the work has been properly designed and carried out, and finally converts the whole of the works.

The author proposes to take as a groundwork a fairly large electrical installation in a shipyard and marine engine works on the North-East Coast with which he has had the pleasure of being very closely associated, to give a short description of it, and comment on various points raised. Thus, even if there is nothing new about the installation, he hopes that room for discussion will be opened up, and that, at any rate, he will be able to learn something from the discussion. This particular installation is, as you will probably agree, rather a good example of

those which have been built up in sections, without having foreseen and provided for the possible magnitude of the installation when laying down the first portion of the plant, and shows defects, but it teaches useful lessons by the very reason of its defects.

DESCRIPTION OF WORKS.—The works premises consisted of :—

(1) A marine engine and boiler-building shop, about 240 feet long by 170 feet wide, divided lengthwise into four bays, viz., a small machine shop for the smaller machine tools, store, and fitters' gallery above, in the north bay; a bay for erecting the marine engines, and containing the larger machine tools, shaft lathes, vertical planers, etc.; a bay for building marine boilers; and a fourth bay for blacksmiths.

On the south side of the engine works was a boiler yard, where funnels, smoke boxes, etc., were built, and at the south-west corner of the boiler yard was the pattern shop.

The power-house was situated on the south side of the engine works, and at its west end, at the top of a steep embankment.

(2) East of the engine works was the shipyard, containing three berths, and all the scattered machinery and stock natural to a shipyard. At the west side of the yard was a joiners' shop and saw mill, containing a large frame saw for cutting up logs, and other machinery.

(3) At the extreme east of the shipyard was the fitting-out quay, where ships, after being launched, were brought to have their machinery put on board and to be finished off ready for going to sea. On it stood a building about 85 feet by 35 feet wide, containing a fitting and blacksmiths' shop, a plumbers' shop, riggers' and shipwrights' stores, etc. On the quay there was also a steam-driven 100-ton jib crane, used for lifting machinery and boilers on board ships lying at the quay.

(4) There was also, north of the engine works and west of the shipyard, the general offices, a building about 90 feet square and containing two floors.

Between the offices and the engine works was the brassfoundry, a building about 80 feet by 70 feet, containing the brassfoundry and a brass finishers' machine and fitting shop, stores, etc.

The installation of electricity was begun ten or twelve years ago in the engine works, when a compound wound dynamo of about 22 kilowatts at 110 volts output was put down to run off the shop shafting and drive two overhead cranes, one, a 30-ton crane, in the boiler shop, of the three-motor type, and one, also a 30-ton crane, in the erecting shop, of the single motor type, driving the different motions by belts run off a common countershaft with fast and loose pulleys. The other cranes, a 10-ton and a 30-ton, in the erecting shop, and a 10-ton and a 40-ton in the boiler shop, were driven by a square shaft running the whole length of each shop.

The next addition to the electrical installation was when the present offices were built. They were lighted electrically at 100 volts by a secondary battery, charged by a dynamo driven from a gas engine and placed in a room under the joiners' shop, which adjoined the offices.

Shortly after this, the subject of electric driving, which had often been mooted, was once more seriously discussed, and it was decided to convert the engine works to electric driving, as the shops were under-

powered. Plans were made and the work was put in hand. A power-house was formed by building a retaining wall at the embankment on the north-east of the engine works, and extending the old engine-house, which was at the top of the bank, towards the east, forming a building about 60 feet long by 35 feet wide. In it were laid down two direct-coupled 220-volt continuous-current compound-wound generators and triple expansion enclosed engines, each of 168 kilowatts output at 380 revolutions per minute. These two were placed in the middle of the floor space, and room was left for another set of the same size on each side of the two sets, which sets were afterwards added. The distance of the engines from the boilers was about 100 feet, the main steampipes being led inside the wall of the engine works. A surface condenser of 1,200 square feet of tube surface, with steam-driven Edwards' air pump and circulating pump, was laid down, and a Klein water cooling tower to deal with 12,000 lbs. of water per hour was erected outside the power-house, on the south side.

The main switchboard had three panels (one spare), with an automatic overload cutout for the generator, main dynamo switch, ammeter, voltmeter, and equalising switch on each panel, while a main pair of bus-bars, off which the circuit switches were taken, ran right across the board. A 3-ton overhead hand traveller, running the length of the power-house, was put up. Steam was supplied at 160 lbs. working pressure from two multitubular marine type boilers, with about 1,350 square feet of heating surface, and fitted with mechanical stokers and feed-water filters. The arrangements for feed-water heating were crude, consisting merely of leading the exhaust steam from two horizontal Tangye pumps, used for supplying the hydraulic accumulator, into the storage tank for the softened water. The water softener itself was of the Archbutt-Deeley type, capable of dealing with 600 gallons per hour. The work done by the 110-volt plant before mentioned was, of course, put on to the central station plant, the motors on the cranes being converted to 220 volts.

Distribution and Wiring.—The distribution throughout was on the two-wire system.

Both power and lighting circuits were taken off the same pair of bus-bars on the main switchboard, to distribution boards in various parts of the works, from which sub-circuits were taken to motors and lights. In some cases motors and lights were kept on separate circuits, the distribution boards for motors consisting of a pair of bus-bars on slate with double-pole fuses for the main feeders and a double-pole fuse to each sub-circuit. The lighting boards had arc lamp switches and main incandescent circuit switches, as well as double-pole fuses, to each sub-circuit and to the main feeders.

In the case of isolated buildings, viz., the pattern shop, quay shop, brassfoundry, and shipyard blacksmiths' shop, the same distribution board was used for both power and lights, with one pair of main feeders, and, although there was considerable relative fluctuation of the motor load in these places, there was no flickering of arc lamps sufficient to cause appreciable difference in the lighting of the place. Probably, if the generators had been shunt wound, flickering of lights would have

been more noticeable, but even then it is so slight as not to justify the extra expense of installing separate mains for lights and motors. All conductors, whether main feeders or sub-circuits, were insulated, as a rule, with insulation graded at 600 megohms insulation resistance, for the reason that it is impossible to handle and dangerous to work near to bare conductors, and "aerial" conductors are dangerous from their apparent safety and the ease with which their slight insulation disappears in patches.

A very good instance of the advisability of insulating main feeders occurred in 1901, when a disastrous fire gutted most of the engine works. All the cables to the shipyard (twelve in all, of which the heaviest pair were $\frac{61}{\cdot 12}$) were run along the engine works roof before the fire, and, to allow of rebuilding, were moved after the fire on to temporary poles across the boiler yard. In view of the work necessitated (which could only be done at week-ends, when the shipyard was shut down) in getting these cables back on to the roof, and their inconvenience when there, it was decided to lay them underground in the boiler yard. A cast-iron trough was laid, the cables were placed in it and filled in with bitumen while they were alive, a job which could not have been accomplished with aerial or bare conductors without stopping the shipyard and causing very serious loss.

In engineering works, where it is essential that work should be carried on uninterruptedly, it is important that a system of wiring, such as the distribution board system, on which any section or subsection of the electrical apparatus can be easily isolated, should always be adopted. Joints in main wiring should not be made, if possible. If they are inevitable, double-pole fuses should always be inserted at the joint. Earths on the system, if neglected, raise the repair cost bill very much, to say nothing of loss by stoppage due to breakdown, and it is important that as soon as a fault comes on it should be located at once, and the first possible opportunity taken to isolate and put right the faulty section. This is a much easier matter where it is only a matter of drawing fuses to isolate any portion of a circuit.

It might have been advisable to have wired the lights on 220 volts with a middle wire, *i.e.*, 440 volts between the outers, but the author thinks it is very doubtful, as arrangements would have had to be made for balancing, and the cost of this, in an installation of this size, would probably have more than outbalanced the saving in copper. In addition to this, the load, when the first installation in the engine works was laid down, was carried by one dynamo, so that the three-wire system was impracticable, and later, when two or more dynamos were required, the advantage of the higher voltage across the outers was of no avail, as the heavier cables required for the 220-volt two-wire system were already installed.

TYPE OF ENGINES FOR GENERATING PLANT.—The choice of motive power for generating current depends largely on local circumstances—the price of coal, water, etc. Where water power sufficient is available, it is the least costly in running expenses, but as water power is so infrequent in this country, it need not be discussed. Gas and oil driving seem to be coming more or less into use, but, except in the case of

works with blast furnace plant, where an enormous power, which would otherwise go to waste, is at hand, or where the output is big enough to justify a special gas plant, of the Mond type, probably does not successfully compete with steam. Where steam is used, the high-speed direct-coupled enclosed engine takes a lot of beating. If coal is very dear, and the load on the plant very variable, it may be advisable to put in slow-speed engines, with Corliss or similar valve gear, so that every possible ounce of steam may be saved up. But the capital cost of a slow-speed engine is very much greater than that of a high-speed one, and it takes up much more room, which considerations may outweigh any increased economy.

It is a mistake to think, as some people do, that a high-speed enclosed forced lubrication engine requires an inordinate amount of attention, or that it is beyond the power of an engineman who has been accustomed all his life to the old slow-speed D valve engine to manage it satisfactorily. It is extremely simple, and if care is taken to see that the oil is kept right as to quantity, that it is drained of water, and changed and filtered at required intervals, it requires very little attention beyond taking off the doors occasionally to see that nothing is coming loose, and a thorough inspection, say, every six months or year. It will run all right with very much less attention than a slow-speed engine with complicated valve gear. The author has had no actual experience of steam turbine driving for large generators, but is inclined to think that there is very little to choose between them and reciprocating engines, the balance, if anything, being in favour of the reciprocating engines. The steam efficiency of turbines seems, as a general rule, to be slightly less than that of well-designed reciprocating engines, though this is a question which seems to have been lately well thrashed out in the columns of technical papers.

In selecting a suitable size of unit to adopt for an installation, first of all, the loads for all portions of the day and night, for power and lights, should be calculated out. In doing so it must be remembered that in altering driving arrangements, it is possible, in the majority of cases, to speed up tools of all kinds, and increase their output; this adds to the power required to drive them. The size of the unit should be based on the minimum regular load required, and should be, if possible, such that, whatever the load is, the generating plant, or such portion of it as is running, is running as near to full load as possible. A spare generating set, over and above the plant required for the maximum load, should be laid down. No hard and fast rule can be laid down for the size of the generating units, but it is generally possible to manage so that the number of units running at full load can be altered to suit the work's requirements, without making their size too small for good efficiency or the cost of the stand-by plant unreasonably great.

MAIN SWITCHBOARDS.—The type of main switchboard built and supplied by the leading manufacturers for installations such as that in the works under discussion is so well known that it seems rather unnecessary to mention them. There is no doubt that the small panel system, by reason of the easiness of extending the board, ought to

be used. The generator panels should be fitted with main dynamo switches and fuses, automatic overload circuit-breaker, ammeter, voltmeter, recording meter and the necessary paralleling switches for each dynamo. The dynamos feed on to a pair of main bus-bars, off which the circuits are tapped. The circuit panels should have double pole switches and fuses for each circuit, with preferably an ammeter in each circuit. The author does not think that overload circuit-breakers are necessary on every circuit, and where it is advisable to introduce them in the circuit, as, for instance, in crane circuits where there are bare trolley wires liable to be short circuited, it is probably best to put them in the shops where the circuits are doing their work, so that in the case of a short circuit occurring the switchboard attendant does not try to switch them in circuit again, and so perhaps bring out the dynamo circuit-breaker. A very necessary fitting on a switchboard is an earth lamp with a two-way switch connected on to the bus-bars. It can then be seen at once whether any earths exist, a thing that is not always bothered about, if some one has to take the trouble to rig up a lamp with a couple of wires and test at intervals.

Motors.—The motors in the engine works and shipyard used for driving the constantly-running machinery were all shunt wound, and of the enclosed or semi-enclosed type. The sizes varied from 6 H.P. to 40 H.P., and the standard sizes adopted were: 6, 10, 15, 20, and 40 H.P. Wherever possible any new motors put in were of these standard sizes, so as to keep spare parts to a minimum and interchangeable. The motors on three-motor cranes, and where driving single reversible machines direct, such as plate rolls, were series wound. The total rated horse-power of the motors, in the engine works, brass-foundry, and pattern shop, was 476, the total in the shipyard being 568. In the engine works, machine and boiler shops, except in the cases of the large machines, such as the big vertical planers, plate edge planers and boring mill, etc., all the tools were driven off lines of shafting by a single motor. In the case of the large lathes for turning propeller shafts, the conversion of which took place before the author's arrival on the scene, this was probably a mistake. In the extensions of the engine works, now taking place, all the big lathes will be direct driven by separate motors with speed regulation.

At the time of the installation of electric power, large use was made of drills and chipping tools driven by compressed air, and the author experimented with portable hand electric drills, for the purpose of comparing them with the pneumatic, in weight for power, cost, and efficiency. The conclusion he arrived at was that, for holes up to about $\frac{3}{8}$ in. to $\frac{1}{2}$ in. in cast iron, the electric drill was superior to the pneumatic in first cost, cost of running, efficiency, and weight for power given. For holes above that size, the first cost of the electric drill gets much greater than that of the pneumatic, its efficiency is much higher, and its weight for power becomes prohibitive in a crowded shop, or where the drill has to be moved about much. It may be interesting to give a few figures, from tests taken, as to the power absorbed by tools, etc.

Turning Wrought Iron Propeller Shaft.

Tool.	Lb. of Metal removed per Hour.	Cutting Speed, feet per min.	Cut.	Traverse.	Nett B.H.P.	Lbs. of Metal per B.H.P. per hr.
No. 1	284	28	·5 in.	$\frac{3}{32}$ in.	8	35·5
No. 2	284	28	·5 in.	$\frac{3}{32}$ in.	9	31·6

Planing Edge of Steel Boiler Plate $1\frac{1}{4}$ in. + $\frac{1}{32}$ in. thick.

Test.	Depth of Cut.	Cutting Speed feet per min.	Lbs. of Metal removed per hour.	Total B.H.P.	B.H.P. in Cutting.	Lbs. of Metal per B.H.P. per hour.	Remarks.
A	...	13·5	...	6·75	...	...	Tool running light.
B	$\frac{1}{16}$ in.	13·5	221·3	28	21·25	10·4	...
C	$\frac{3}{32}$ in.	13·5	331·7	34	27·25	12·15	...
D	$\frac{1}{32}$ in.	13·5	110·7	18	11·25	9·85	...
E	$\frac{3}{64}$ in.	13·5	165·8	25	18·25	9·01	...
F	$\frac{3}{32}$ in.	13·5	...	About 45	...	...	Tool very blunt.

These figures were taken on the ordinary work done by the planer. The tool was of ordinary tool steel, and it was worked with feed and speed at which it would remain fairly sharp for about an hour. It will be seen from the reading F what a very great difference a blunt tool will make, this tool being one that had been taken out for re-grinding. As will be seen, it was useless for anything like a heavy cut, the motor fuses blowing at once.

These figures are perhaps not of much value as far as the powers required for any individual machines are concerned, but they are useful to form a rough estimate of the power required for groups of tools, which is a different thing. The starting currents for Nos. 12, 13, 14, were taken to show the heavy torque required to start the class of machinery with heavy moving parts, such as that used in a shipyard.

The usual average of time taken to bring these machines from rest to full speed would be 20 to 30 seconds, and in all three cases it will be seen that the peak of the current taken at starting was considerably over the rated full load current for the motors, although, looking at the other figures, one might think that smaller motors could be safely used. As the speed of these machines need not be very constant, and to help at starting, it is better to have a few turns of series winding on the motor field coils.

The author thinks it advisable, as machinery of this class is, as a

No.	Machinery driven by Motor.	Starting current (maximum)	Minimum B.H.P.	Maximum B.H.P.	Normal Working B.H.P.	B. H. P. absorbed in Shafting.	Remarks.
1	1 24 in. planer, 1 9 in. planer, 1 24 in. circular saw, and Joiners' Shop Machinery driven off shafting	...	6·25	25	10–12	6·25	About 30–40 hands in shop.
2	1 30 in. wood planer, 1 set grindstones for sharpening, driven off shaft	...	...	16	8–10	4·75	
3	1 large frame saw, 2 30 in. circular saws, driven off countershaft 20 ft. long ...	...	...	36	12–15	6.5	
4	1 30 in. rotary planer, 1 set small grindstones, 1 24 in. circular saw, 2 small lathes, 1 facing machine...	...	...	17	8–10	4·75	
5	1 30 in. band saw, 1 30 in. circular saw, 1 24 in. rotary planer, 1 6 ft. grindstone, 40 ft. of shafting	...	...	31	7·5 to 10	4	About 25–30 hands in shop.
6	1 6 ft. grindstone, 1 slotting machine, 5 or 6 small lathes (metal)	...	...	25	14–16	...	
7	About 20 small lathes, etc., 140 ft. of shafting, 3¾ in. dia.	...	8·25	20	13	7·25*	* No belts on main shaft. =·0518 H.P. per running ft. to drive shaft
8	1 3 ft. planer, 1 drilling machine, about 10 lathes, screwing machines, etc. ...	...	7	18	10–12	6	
9	1 pneumatic 10 cwt. hammer, 1 blower for 24 fires	...	12	20	...	...	
10	1 Blower in Smiths' shop, feeding 1 7 in. nozzle flanging fire, 2 4 in. nozzle ditto, 20 hearths	...	6	10	8·5	...	
11	1 Blower, feeding 46 Smiths' fires 22 working	...	...	...	20	...	
12	4-sided punch, having 2 1½ in. punches, and 2 8 in. × 8 in. square punches ...	71 amps.	4	16	5·5	...	Motor rated at 15 H.P.
13	1½ in. punch and shears	57 amps.	3	14	5	...	„ „ 15 „
14	1 in. double Cameron punch	48 amps.	3	8	6	...	„ „ 10 „

rule, scattered, intermittently used, and generally started and stopped by any man who may want to punch a hole in a plate, and knows nothing about electricity or electric driving, to keep well on the liberal side when selecting sizes of motors, so that rough usage is less liable to cause breakdowns. Three or four hours' stoppage of a single punching machine at a busy time may cause more loss than the loss in a year due to the less efficient running of a motor larger than is absolutely necessary. Wherever several machines were grouped within a short distance of one another, the plan was adopted of placing the double pole switches and starters for the motors of the group in a cabin, at a point visible from all the machines, and putting a boy to do all the starting and stopping of the machines in the group, at signals from men going to use the machines.

In all cases of driving separate punching and shearing tools, belt drives were employed in preference to spur or chain gear. When starting, a heavy torque is required, and a belt allows of a certain amount of slip till the machine has got up speed, and relieves the motor of some of the strain it would have were it rigidly connected to the gear. Also, in the case of punching, the motor has very little to do with the actual punching. It gives the moving parts their inertia, and this inertia carries the punch through. Even during the quarter second or so taken by the punch to travel through the metal, the speed of the machine is affected, and here again a belt drive is advantageous, for the belt will slip, and reduce the momentary load thrown on the motor, where rigid gear would give it a big shock, to say nothing of the risk of breaking teeth on gear wheels, a much more serious matter than a broken belt. The author has seen a heavy four-foot cast-iron spur wheel, with teeth about 1½ in. thick at the root, and 6 in. wide, with very heavy arms, rim, and hub, smashed in four or five pieces on one of these machines, in shearing an angle bar, while the belt, although without guides, did not even come off the motor pulley and flywheel. In the case of shearing machines, the working stroke, *i.e.*, the period when the blade is actually cutting through metal, lasts for a much longer proportion of the total stroke, but the conditions are very similar, and the belt drive gives elasticity which cannot be got by direct spur driving. The stroke of a shear blade is less of a blow and more gradual than in the case of a punch, and lasts long enough to appreciably overcome the inertia of the moving parts, the motor thus having a harder job than when punching.

STARTERS.—Wherever possible, liquid starters and controllers were used. For non-reversing machinery a type was used with an automatic release, which merely consisted of a solenoid coil, in the shunt circuit, which held the dipping blade down. If current was shut off the blade was released, and a spring caused it to fly up.

No overload release was used. These were tried on some metallic starters, but were found to be too "kittlish" for use in a place where non-stoppage of work is essential. A momentary overload which would not seriously affect a motor, and is of too short duration to blow the motor fuses, makes the overload release act, and stops the motor until somebody can be found who knows where to look for the cause of

stoppage and how to put it right. A fuse is reliable enough to act when the overload is serious, or of long duration. Each motor was fitted with a double pole main switch, double pole fuse, and starter, in addition to the double pole fuse on the distributing board, so that there were two sets of double pole fuses to safeguard each motor.

The author does not deny that there are excellent metallic starters on the market, although many of them are badly arranged, badly divided off, and too light for their work. There is, however, no fault to be found with some, on whatever ground, as a starter. It is not, however, on technical grounds that the author prefers liquid starters, as on the general grounds of the use to which they are put. As a rule it is inevitable, without overmanning the electric staff grossly, that in a works of this description, motors have mostly to be started by unskilled men, or rather, men who know nothing about electrical machinery. Even if the shop foremen is the only non-electrical man allowed to start a motor, there are plenty of shop foremen who are quite capable, after dozens of lessons, of putting in the main switch, cutting out all the resistance with one vigorous shove, or even of reversing the order of those operations, and then cursing because the motor does not start.

The liquid starter, to the uneducated mind of the ordinary workman, more resembles a stop-valve; he can see something is happening, by the bubbling of the solution. If it bubbles too much he is moving too fast, if it doesn't bubble at all, and the motor doesn't start, something is wrong and he sends for an electrician. But, with the majority of metallic starters, a handle projects in some form outside a closed box, and the man starting the motor cannot see anything going on, beyond flashing at the contacts, which probably takes place under any circumstances. So he doesn't take so much interest, and moves the handle at the pace which seems most expedient to him. In addition to this the liquid starter can be constructed in a much simpler manner, and with fewer parts to get out of order, than a metallic starter, which makes repairs easier and cheaper.

In the case of cranes and other reversing machinery the same thing applies. The liquid controller, to the mind of a man accustomed to steam, resembles a stop valve, and if he treats it as he would a steam engine stop valve he will not go very far wrong. For cranes, etc., the tramway controller is probably as capable of withstanding rough usage as any liquid controller, but its initial cost is high, which will, where low prime cost is an object, throw the balance in favour of the liquid controller.

A great advantage of the liquid controllers is that all making and breaking contact is done on the surface of the liquid, and so sparking at metal contacts is avoided. The chief objection to the liquid starter, viz., that the solution must be of the necessary strength and quantity, and that it is liable to creep and make things in a mess, has no grounds in a works where an electrical staff must be kept, and where some one can be made responsible for examining and attending to them all at stated intervals.

CRANES.—The electric cranes in use were all in the engine works and brassfoundry, as follows:—

SITUATION.	Maximum Load Tons.	MOTOR B.H.P.			Controller.
		Hoisting.	Travelling.	Traversing.	
Brassfoundry	5	6	4	3	Liquid
Erecting shop	30	15	10	5	Metallic
"	10	6	4	2	Liquid
Boiler shop	30	14	8	4	Liquid
Unloading gantry ...	20	15	10	4	Liquid
Boiler shop	40	30H.P.	single	motor	...
"	10	20 "	"	"	...
Erecting shop	20	15 "	"	"	...
Turning shop (2) ...	$\frac{3}{4}$	1	1	...	Metallic
Upstairs fitting shop (2)	$\frac{3}{4}$	1	1	...	Metallic

Besides these there were one or two small hoists in the shipyard. All the three motor and two motor cranes were fitted with automatic brakes, to act when current is shut off.

The trolley wires, except in the case of the brassfoundry, where an old solid rod trolley wire was used, were of stranded hard drawn copper, and were both mounted on one side of the shop, to save the expense of a double set of brackets, and to minimise the number of holes drilled in the girder work. The current collectors were all of the sliding shoe pattern, which lifted the trolley wire off the brackets as the crane passed along. Collectors of the wheel type were tried, but these were found very liable to jam, and wear the trolley wire badly, and were all replaced by long shoes.

At first the crane circuits were protected by double pole fuses only, but one or two short circuits occurring, owing to careless men putting oil-cans, etc., down on the two trolley wires and bringing out the generator circuit-breakers in the power-house; all crane circuits were protected by overload circuit-breakers. After they were fitted, they answered perfectly satisfactorily. The author thinks that all crane circuits, where bare trolley wires are used, should be fitted with automatic overload circuit-breakers, as in the case of a dead short, fuses heavy enough to stand the ordinary load act too slowly, and there is a danger of bringing out main circuit-breakers when these are used. In the case of ordinary motors, driving tools of any kind, a circuit-breaker is unnecessary. He is unable to remember a case of a short circuit on a motor other than cranes, bringing out the dynamo circuit-breaker, and the rareness of the occasion justifies the leaving off of circuit-breakers on all circuits (other than crane circuits).

Stranded trolley wires were used in preference to solid ones, because of the greater ease of handling and repairing. However badly a stranded wire is burnt by short circuiting, it is possible to patch it up, so that, at any rate, it can be used till a new one can be run, whereas if a solid wire gets burnt through, or nearly through, the chances are it

cannot be used at all again, and the shop cranes have to stand till a new one is put up. It was the author's practice always to keep ready to hand a spare pair of trolley wires for the erecting and boiler shops (which were of the same length), for the cranes are the life of a busy shop, and without them the shop soon comes practically to a standstill.

SPARES.—In converting a works of any size to electric driving, as a rule not nearly enough attention is paid to the matter of spare gear. No man, nowadays, hesitates to insure his premises and goods against fire, and to pay heavy sums annually, so that he may not lose, or that his loss may be a minimum, in the case of fire breaking out. At the same time he may be firmly convinced that a fire could not possibly happen in his works. Spare parts are an insurance premium, paid to cover the risk of serious loss from stoppage of work, due to breakdown of machinery. Thirty or forty years ago, and even with some firms to-day, steam engines and other machinery were only in very exceptional cases built so that the parts of any two machines were interchangeable, without an excessive amount of fitting, even though the machines were supposed to be exact duplicates in every dimension. But with present-day electric, steam, or gas machinery, as of course with many other classes of present-day machinery, all parts which are likely to require renewal, or are likely to break down in case of anything untoward happening, can be made exactly interchangeable for machines of the same type and size.

For the generating sets a stand-by plant is necessary, and this is a complete set of spares by itself, so that, in the case of the dynamo, no spare armature is wanted, nor need any other spare parts be kept, except small parts, a set of piston rings, a complete set of governor or other springs, carbon brushes, and any other special part that might require renewal. It is advisable, where possible, when deciding on the correct plant to buy, to keep the units of exactly the same size and type, and, moreover, of such a size and type that it will suit for any future units that may have to be laid down for possible extensions. Then one set of spare gear will fit each and all of the units. This is not always possible, but unless there is a strong reason against it, the units ought to be kept identical, for not only are spare parts reduced to a minimum, but the attendants get more familiar with, and handle more easily, a number of identical units, than a heterogeneous collection of machines.

A spare armature should be kept for every different size motor in the works. Great improvements have lately been made in the manufacture of motors, and as a machine they are now, mechanically and electrically, perfectly sound. But accidents will happen. As an instance of an accident, the author has known cases of a playful lad throwing a nut, or some such handy missile at an equally playful companion, and hitting the open door of a motor, the nut getting jammed between a pole-piece and the armature, fireworks and a stoppage resulting. As everybody can appreciate, very serious losses may result from the stoppage of even a small section of a shop, if it is a case of rewinding an armature or waiting for a spare one to be sent off from the manufacturers, whereas, even in the cases of motors, up to say 30-horse-

power, it is, as a rule, only a case of waiting one to three hours to put in a spare armature that is ready to hand.

A small, though important point, about all armatures is, that the pulley should be fixed on by a set-screw and feather key, or in some manner so that it may be easily removed from the shaft, to prevent loss of time in getting out a stubborn driven key. It therefore behoves the buyer of plant to use as small a number of sizes of motors as possible, and have a spare armature for each size. It is better to underload a motor in a case where only one or two of the correct size would be wanted, so as to keep to the standard size, and have the use of the standard spare gear for that size. Spare brush gear is also a necessary for each size of motor, and may save a good deal of time in renewal work, which must necessarily be done in overtime, when the shop is not working.

Recording of Loads.—The methods that were adopted for registering current generated and consumed were chosen so that as much information as possible might be obtained from the readings taken, and at the same time the instruments and readings might be easily understood by the working staff. In this case the system consisted of three compound wound dynamos, feeding in parallel on to a pair of common main bus-bars, off which bus-bars all circuits were taken through double-pole switches and fuses. An automatic circuit-breaker, with magnetic blow-out arrangement, protected each generator. The current fed on to the bus-bars by each of the three generators was registered on a recording low potential ammeter on the main switchboard, with a paper speed of one inch per hour. As the shipyard was worked as a separate department from the engine works, the switches for the shipyard circuits were all mounted on a separate panel of the main switchboard, and for the purpose of determining the consumption of current by the shipyard, an ammeter of the above type, with paper speed of one inch per hour, registered the aggregate current passing to this panel. A portable ammeter of the same type, with a paper speed of six inches per hour, was kept for the purpose of testing loads on motors, or any particular circuit, etc. This speed, one-tenth of an inch per minute, was ample to show the exact durations of the load, as well as its magnitude, and the instrument was very useful.

The paper recording instrument was used in preference to the summation type for recording the dynamo current and the current used by the shipyard, because of the greater amount of information to be obtained from the charts. On them could be traced the exact nature of the load at any minute of the day, and any apparent irregularity could be inquired into. Also it acted as a check on the regular rotation of running of the three dynamos, the load during portion of the day being small enough to be carried by two machines, the third being put in when the lighting load came on, and it was an object, as far as possible, to distribute the work evenly between all the machines.

All records were filled in books kept for the purpose, the working up of the results being extremely simple and done as follows:—The total area enclosed by the line marked by the pen and the zero line was measured by a planimeter, registering in square inches. This area

multiplied by a constant depending on the paper speed, the breadth of the paper and its graduations, gives the total ampere hours.

Thus :—Suppose the paper speed is 6 in. per hour, paper breadth is 3 in. and graduated to 200 amperes, area of card 12·5 square inches

$$\left(12{\cdot}5 \times \frac{200}{3} \times \tfrac{1}{6}\right) \text{ (= total ampere hours)} \times 225 \text{ (voltage)}$$
$$= 32{,}500 = \text{total watt hours.}$$

This method of recording, although it may be open to the charge that it is not as accurate as if the watt hours were recorded direct on a watt-hour meter, is, nevertheless, accurate enough for all purposes, and possesses the advantages that it is simple, and one can see exactly where the various loads are coming from and going to.

Relation of Current Demand to Rated Motor Power.—In the shipyard, where there was only one small two-ton crane, the aggregate brake horse-power of the motors of all kinds employed was 553. Taking 4 amperes at 220 volts as being required to give one brake horse-power from the motor, the total current required if all the motors were working simultaneously at full load would be 2,212. Let us call this the rated full-load current.

Then from observations taken :—

$$\frac{\text{Maximum actual demand by motors}}{\text{Rated full-load current}} = \frac{800}{2{,}212} = {\cdot}362.$$

In the engine works and brassfoundry, etc., the aggregate rated brake horse-power of the motors was 504, but this included :—

Two 30-ton three motor cranes.	One 40-ton single motor crane.
One 20 „ „	One 20 „ „
One 10 „ „	One 10 „ „
One 5 „ „	

The engine works rated full-load current was therefore 2,016 amperes and the actual maximum demand about 700 amperes.

∴ for the engine works :—

$$\frac{\text{Maximum actual demand by motors}}{\text{Rated full-load current}} = \frac{700}{2{,}016} = {\cdot}347.$$

Generating and Coal Costs.—In giving tables and figures for generating costs, etc., the author does not claim that the figures are by any means what they ought to be, although they will probably compare favourably with a great many large private installations in works. They serve to show, however, in this particular case, wherein the defects in the generating plant lay, and in a general way, on which the author wishes to lay stress, the enormous importance not realised by a great many private owners of installations, of collecting and tabulating all possible data, so that any weak point in the installation or possible improvement may be spotted at once, and acted on as may be necessary. Of course, in all public or private supply stations, where the business is solely generation of electric current, accurate figures and data are kept and published, and the general run of the cost figures for

generating current are well known and accessible to any one who reads the technical papers.

Unfortunately, or fortunately, the installation which the author has made the basis of his remarks was put down piecemeal, and prior to his advent on the scene, it was deemed advisable to lump all electrical generating and upkeep costs with the ordinary works maintenance cost accounts. In addition to this, the feed-water system for supplying water to the steam boilers for driving the electric plant was common to another boiler used for driving steam hammers, feed-water pumps, and a steam-driven set of accumulator pumps. Steam from the boilers raising steam for the electric generators was also taken for driving two air-compressors of about 25 H.P. apiece. The whole of the water softened was not used for the electrical plant boilers, some of it being sent down to the shipyard for feeding an auxiliary boiler there. In spite of these difficulties the author took all possible readings and observations with the object of ascertaining exactly the proportion of coal and water used for the generating of electric current, and managed to fix down pretty accurately the proportions he wanted. Although, therefore, he cannot say that the figures are scrupulously exact, they are reliable, and serve the purpose for which they were intended, viz., to find out, in detail, what the generation of electricity was costing the firm, and whether the figures arrived at represented the best practice under the circumstances. The figures given are not picked in any way, but are taken from the electric costs book, and are taken from five continuous months during which both double (*i.e.*, night and day) and single (*i.e.*, day only) shifts were worked.

Generating Cost Details per Board of Trade Unit.

MONTH. SHIFT.	Sept. Double.	Oct. Double.	Nov. Double.	Dec. Single.	Jan. Single.
Coal	·441	·407	·345	·422	·421
Water	·026	·022	·022	·023	·024
Wages	·082	·084	·084	·117	·115
Stores and Repair Material, etc. ...	·013	·027	·105	·053	·058
Wages for Repairs	·077	·092	·092	.087	·090
Works Cost	·639	·632	·648	·702	·708
Taxes, Rents, and General Charges...	·092	·101	·117	·135	·130
Interest and Depreciation	·202	·186	·188	·280	·289
TOTAL COST	·933	·919	·953	1·117	1·127

The capital outlay per kilowatt was £23 4s. The average price paid for coal was 11s. 6d. per ton.

Now let us examine these figures. The cost per unit of coal in September is nearly 50 per cent. of the total cost per unit. Referring to the coal sheets we see that the total coal used during the month for electrical purposes was 314·1 tons. The total output of the plant (double shift) was 98,274 Board of Trade units. This works out at 7·175 lbs. of coal per B.T.U., or, taking 82 per cent. as the average combined efficiency of engines and dynamos, 4·39 lbs. of coal per 1 H.P. per hour, or, again, 5·35 lbs. of coal per electrical horse-power per hour. This seems to be higher than it ought to be, a thing the author expected to find, for, as before said, the feed-water heating arrangements were very defective, and there was a run of about 100 feet for the main steam pipes from the boilers to the engines, and this, although the pipe was covered with non-conducting composition and run inside the building, must have been a source of considerable condensation. The cooling tower had also for some time been too small for its work, and, in consequence, the condensing water returned to the condenser at too high a temperature to keep a proper vacuum, which would, of course, cause a rise in the coal consumption. However, an investigation was made to see whether any immediate steps could not be taken to reduce the coal consumption, with the result that it was found that the mechanical stokers on the boilers, although they reduced smoke, were, from whatever cause, throwing the coal badly, a good deal of hand firing having to be done, as well as admitting too much air to the furnaces. They were, therefore, as hand firing could be done without increase in the number of firemen, dismounted and hand firing resorted to, with the result that, in October, the cost of coal per unit is reduced by nearly 8 per cent., the coal used per electrical horse-power per hour in October being 4·03 lbs., on a total output for October of 106,641 Board of Trade units. This is an improvement, although the figure of coal consumption was by no means as low as it ought to be, and may be, with a well-designed installation.

In November the coal cost is still further reduced. No special reason can be given for this, except that the condenser was re-tubed at the beginning of the month. The cooling water was extremely hard; the inside of the condenser tubes very speedily became coated with a very hard flinty scale, very difficult to remove. In fact, the author has not come across a tube brush or scraper that would efficiently cope with it, and the condenser had to be periodically re-tubed. The coal used per E.H.P. in November worked out at 4·18 lbs. per hour, on a total output of 104,977 Board of Trade units.

None of the other figures for the first three months call for any special comment, except, perhaps, the high figure for stores and repair material in November. This was due to two new sets of piston rings being charged, and also examining and overhauling the cylinders of three engines in that month. Depreciation was calculated at 5 per cent. on the total capital outlay on generating plant. At the end of November the night shift was knocked off. First let us see what reduction is made in the output of the electrical machinery.

The average output per month for September, October, and

November, when two shifts were running, was 103,297 Board of Trade units. The average for December and January, with only a single shift, was 71,580 Board of Trade units, or a reduction of, roughly, 30 per cent. of the output due to the night shift being stopped. It may be objected that December and January are, owing to the holidays, broken months, and therefore the comparison is hardly fair, but that does not affect the broad principles which the author is seeking to prove. As a matter of fact, as will be seen from a comparison below, the actual number of hours during which the electric plant was running was about 60 per cent. in December of what it was in November. This high proportion was due to a large amount of overtime worked during December in the shipyard, and would be expensive running for the electric plant.

Returning to the cost sheet, we see that in December and January the coal cost per unit has risen again to nearly what it was in September, although it is not such a large proportion of the total cost (about 35 per cent.). To see exactly how this extra coal used was to be accounted for, and what proportion went to banking up, etc., the coal used in the electric plant boilers was accurately measured for every hour of the day for a number of days, as well as the output of the dynamos during each hour of the day. The figures given below represent the mean of the daily readings taken.

Coal used during different portions of the day.

	Before 6 a.m.	6 a.m. to 8 a.m.	8 a.m. to 9 a.m.	9 a.m. to 12	12 to 2 p.m.	2 p.m. to 5 p.m.	5 p.m. to shut down.	Banking up.
Total lbs. Coal used ...	2,987	3,920	933	3,593	2,659	3,920	1,960	1,260
Total Units generated ...	97·5	714·25	163	882·92	318·25	870	335·5	...
Lbs. Coal per E.H.P. hour	23	4·1	4·27	3·04	6·23	3·36	4·35	...

The shipyard breakfast time was from 8 till 8.30 a.m., and dinner hour from noon till 1 p.m. The engine works breakfast time was from 8.30 to 9 a.m., and dinner hour from 1 to 2 p.m., so that 8 to 9 a.m. and noon to 2 p.m. were times when the load was light. The reason of the coal consumption being so high between 12 and 2 was that advantage was taken of the light load to clean out the boiler fires during that time.

Now during the actual time the plant was being used, *i.e.*, from 6 a.m. to the time of stopping, the total amount of coal used was 16,985 lbs., or about 80 per cent. of the gross total, for a total output of 3,283·92 Board of Trade Units. This gives us 3·9 lbs. of coal used per electrical horse-power per hour, or, taking into account the coal used in banking up and restarting, 4·7 lbs. of coal per electrical horse-power per hour, as against 4·56 lbs. of coal per electrical horse-power

per hour used in October and November, the two months of double shift during which the boilers were being fired under similar conditions.

During the period of double shift the night load was about five-twelfths of the day load, so that these figures show that the extra coal used per unit in banking up and restarting is not very much more than the increase per unit of coal used during double shift due to the decreased efficiency of the working of the night load. We may expect that, had the night load, while double shift was running, been the same as the day load, the coal used would have come out at about the 3·9 lbs. per electrical horse-power per hour given above as the coal actually used during working hours. We see also that wages for running the plant were increased about 40 per cent. per Board of Trade unit, rents and general charges about 28 per cent., and interest and depreciation about 48 per cent., due to the night shift being stopped.

The following comparison shows the proportion in which the various items were increased or decreased by the stopping of the night shift :—

Comparison between Double and Single Shift.

	November, Double Shift.	December, Single Shift.
Total Output	100	70·5
Total hours run	100	60·2
Total Cost	100	83·0
Cost per Board of Trade unit	100	117·2
Total Coal used	100	86·5
Coal per E.H.P. hour	100	121·1
Total Water used	100	70·0
Total Wages, Electricians	100	72·7
„ Enginemen	100	51·6
„ Firemen	100	100·0
„ Millwrights	100	101·0
Interest and Depreciation per Board of Trade unit	100	148·9
Total Labour „ „ „	100	116·0

The items of proportionate increase of cost on stopping the night hift are, in order of importance, interest and depreciation, coal, and ıbour, which are, of course, just as we should expect them.

The labour and coal are not very excessive, when double shift is running, in spite of the defective condensing and steampipe arrangements mentioned before, but the change in the total cost when single shift only is worked is very marked, which goes to show, what probably all present know, that the nature of the load makes very much more difference to the cost per unit generated of a plant than any mechanical defects or perfections of the machinery used. The author does not mean to imply by that that not much attention need be paid to mechanical and labour-saving details. Very great attention must be given to all details of an installation, so that all apparatus used is of the very best and most economical type, but the refinement of cost-saving machinery may easily be carried so far that some of it saves less than it costs in interest and depreciation, especially in the case of poorly loaded plant, and there is no doubt that this happens so in the case of a great many central stations.

In far too many cases where it is decided to instal electric plant the subject is not understood by any one in the employ of the works owners, and the matter is placed in the hands of a well-known firm of electrical contractors. They will probably supply machinery satisfactory enough in itself, on the scanty information furnished, but, as often as not, not the most suitable class of machinery for the particular circumstances. To get the best results the matter must be investigated thoroughly by an employee of the works owner, who knows exactly, or can find out, the system under which work is carried out, the nature of the probable load on the generating plant, in general, knows the particular set of circumstances under which the plant will have to work, and, of course, knows intimately all the different points about generation of electricity in all possible manners—steam, gas, water, etc.—and transmission of power by electricity.

Above all must all possible data be tabulated, and all costs kept, in such a manner that all fluctuations in loads, consumptions, and costs may be readily seen, and the cause investigated and, if necessary, remedied. This is a most important point. Thirty or forty years ago people would stick down a set of boilers, steampipes, and engines, and connect them up to their shaftings, and never, up to the present day, had they the faintest idea what work they were doing, or what they were costing. But that was in the days when fortunes were made. Nowadays manufacturers have to take orders at under cost prices, and it behoves them to see that, among other things, their methods of generating power are the most economical and the most efficient possible.

As an instance, a few months ago the author had the pleasure of advising the head of a large works to adopt electric driving. On going roughly into the question it was clear that a saving of at least £2,500 per annum could be made in the works expenses, with a capital outlay of about £8,000; and there must be hundreds of works in the country where similar results could be arrived at. In this case the owner had not much idea how much his power was costing him, beyond the fact that he was burning so many tons of coal per annum, and some of that in heating furnaces.

Another very general and also fatal mistake, that is made in con-

verting large works to electric driving, is converting by degrees, and not allowing in the first instance for the maximum proportions to which the installation may extend. Electric driving is now past its infancy, and its performances and capabilities are pretty well known, but, in spite of that, the man who is thinking of converting the whole of his works, taking, say, 2,000 horse-power, will be distrustful, through ignorance, and will convert a portion of the works, taking, say, 200 horse-power. Instead of laying down his power-house, boiler plant, generating units, etc., on the assumption that, ultimately, he will require 2,000 horse-power, he sticks down a little 200 horse-power dynamo in a corner of the shop out of the road, and makes his arrangements so as to spend as little as possible over his "experiment," instead of employing somebody who knows intimately all about his little "experiment" and laying down proper plant. The consequence is that, when he finds electric driving seems to be quite practical and much handier than steam, that nothing explodes or misbehaves itself, although perhaps he has only a general idea that he has made any saving in £ s. d., he decides to convert the rest of his works, and must then face two alternatives: (1) add to the plant he has already bought without regard to its suitability for the larger installation, and so sacrifice economy in running expenses, or (2) disregard (partly or altogether) the plant he has bought, and lay down a complete and up-to-date generating plant and station. In this case his total capital cost is a good deal greater than it would have been had he laid the first plant down on the assumption that he needed 2,000 horse-power altogether. Of course the idea of such a man is that the "experiment" may be a failure and have to be pulled out again, therefore, looking to such a contingency, he wishes to keep his possible loss as small as possible; but, as was said before, electric driving is now well past the experimental stage, and electrical machinery, as now manufactured, is as reliable as, or more reliable than, any other kind. It only needs proper knowledge of the local circumstances to be able to say definitely what is the most suitable plant to lay down in any particular case, its prime cost, and the cost of running it.

Adaptability of Electric Driving.—As a very good instance of the pliability and adaptability of electric driving, rather than with any idea of its being in any way extraordinary, the author introduces a disastrous fire which occurred in the engine works in September, 1901. It was discovered about 5 o'clock in the morning, when a day shift only was working, by men coming in to fire up the boilers, and the net result of it was that a great portion of the engine works was gutted. Fortunately the power-house was unharmed, but the supply mains to the shipyard, which passed along portion of the engine works roof, were damaged. By 9 o'clock in the morning it was possible to get up the shipyard cables for examination, when it was found that very little damage was done, except that the insulation was all burnt off for a considerable distance and one supporting bracket was broken down. This was soon temporarily put in working order, and the supply to the shipyard resumed by midday.

The engine works, however, were in a different plight. The whole

of the small machine shop, erecting shop containing the larger planing, turning, and boring machines, and portion of the boiler shop were gutted. Luckily the new brassfoundry, between the engine works and the offices, was practically completed, and it was at once resolved to convert this into a temporary shop for the smaller machine tools, and let the large machine work out to neighbouring firms. A pair of $\frac{19}{14}$ were at once run to the brassfoundry building, wooden baulks and platforms were erected to support the necessary shafting, and the shafting put up in two sections with two 20-horse-power motors, which happened to be available, with starters, etc., to drive it. Lathes, etc., were wired for and put down with all possible speed. The motors were, without haste, ready to run within two or three days of the fire, and the shafting very shortly after, and, if necessary, all this portion of the work could have been ready in forty-eight hours.

In consequence of electrical power being available, therefore, a few machines which the makers had had in stock were running within about a week of the fire, while within three weeks nearly as much work was being done in the temporary building as had been done in the burnt-out small machine shop. The pliability of electricity was further illustrated in rebuilding the engine works, in the use of temporary arc lamps and clusters, and of portable saw benches, a tool largely used in ship work for sawing joists, flooring, etc., etc. These portable saw benches have, in the works under consideration, almost entirely superseded hand sawing and hand adzing on ships in course of construction, with a large saving in cost.

LIGHTING.—Although in deciding on the number of arc lamps to put in a building each case must be considered from its own standpoint —that is to say, the reflecting power of the surface of the walls, any obstructions there may be, etc., have to be allowed for—the author

	Shop.	Approximate Floor Area (sq. ft.)	Watts per 1,000 sq. ft. of Floor Area.	Remarks.
1	Joiners' Shop	6,000	1,100	All Inverted Arcs
2	Marking-off Loft	4,800	917	„ „
3	Turning Shop	5,400	1,630	Enclosed Arcs
4	Erecting „	13,200	583	„ „
5	Blacksmiths' Shop	7,200	460	Open Arcs
6	Boiler Shop	13,200	500	„
7	Quay „	2,772	800	Enclosed Arcs
8	Plumber's Shop	1,850	600	„ „
9	Pattern „	5,400	1,020	„ „

gives below a few figures for the watts installed in arc lamps alone in various shops. He is inclined to be in favour of enclosed lamps, on the ground that they cost less in upkeep, although not so much light is obtained for an equal consumption from enclosed as from open type lamps.

No. 1 is, the author thinks, the best illuminated shop he has ever seen. No. 3 is rather a dark shop, with a great number of belts. The arranging of the lamps was rather difficult, in order not to leave any badly lighted corners. In addition to the arc lamps there were, in Nos. 3, 4, 6, 7, 8, a number of incandescent hand lamps for use on machinery, inside boilers, etc., where local light was required.

In conclusion, the author wishes to express his indebtedness to Messrs. W. Doxford and Sons, Limited, for allowing him to publish the figures in this paper.

Mr Hall.

Mr. C. J. HALL said he thought it was a very interesting paper, and the author had treated the matter very fully, and no doubt some of the particulars given would be very valuable. He said he had recently been responsible for the electrifying of very large works in Leeds, and the system adopted was identical with the one described in the paper, with the exception that it was an earthed return, and therefore there was only one wire necessary for the crane. The trolley conductor was not stranded, but solid, and he quite failed to see the advantage of a stranded wire, as they were all solid in tramway work. On the completion of the plant it will have a capacity of 1,250 H.P.

Mr. Fox.

Mr. H. FOX said, with reference to the overhead, it was the usual practice to have these bared, and it was rather unnecessary to have them insulated. He said there were many shipyards and large engineering works where the overhead wires were run bare, as the insulating of them carried the cost up unnecessarily. Regarding the crane, he had had trouble with the stranded conductors, and had not used them for the last two or three years; he, however, did not know the exact reason for discarding the same. With reference to the stranded conductors fusing, his experience was that these conductors fused even with a flat shoe, and he had put solid trolley wires up and replaced one or two stranded wires with advantage.

Mr. Rosling.

Mr. P. ROSLING said he thought it a most practical paper, and as the facts were from the writer's experience, they were rather hard to criticise. He failed to see the necessity for the spare set of generating plant insisted on in the paper, because, as Mr. Wraith had pointed out, a good modern high-speed engine required little or no attention, and a modern generator should require less, so that the provision of a complete spare set needlessly ran up the capital cost. He cited the ordinary mill which did not have a spare engine, and said a factory or works run from two or three sets such as the case in point would be far safer from complete stoppage than the ordinary single-engine mill. He thought the motors in the shipyard were rather oversized, because the maximum actual demand divided by the full-load current was 0·362, whereas the average of three shipyards on the north-east coast came out at 0·450, which looked as if the motors could have been reduced in size

Mr. Rosling. by nearly 30 per cent. On page 1001 Mr. Wraith gives the maximum starting current for punch and shears at 71 amperes, 57 and 48. The speaker thought, however, that if a proper starting device had been put in, allowing, say, one minute for starting, smaller motors could have been used, as, the load being due to acceleration, the time was a big factor. On the question of starters, he thought that, if the metallic starter was properly designed, it was far superior to the liquid, as the latter were difficult to keep clean, and there was a very great difference in the resistance of the liquid due to variation in temperature and evaporation. With a high-class metallic starter and an arrangement for limiting the time of switching on, a very ignorant man could be trusted to switch on a motor. He quite agreed with Mr. Wraith as to the adoption of belts instead of gear wheels, and thought them more economical. They could almost always be used—if not direct, with the assistance of a tightening pulley. He thought the author might have included in his labour-saving devices a wattmeter to calculate the amount of current used in addition to the recording instrument.

The paper pointed very strongly to the advantage of the central power station. Firms could get the current from the local station at a more economical price than they could generate it themselves, and extend their electric drive piecemeal, and on completion of the work find they had not spent more than £10 per k.w., against the £23 mentioned in the paper. He understood that the firm in question whose installation they had had described, were now taking some 300 or 400 H.P. from a supply station, instead of increasing their own plant.

Mr. Churton. Mr. T. HARDING CHURTON said there were one or two points he would like to refer to. With regard to the installation, this had been carried out in sections, and had probably not been laid out in the way in which it would have been had it been designed as a complete installation in the first instance. He would have liked to have heard the author's opinion as to the course he would have adopted if he had had the installation to carry out from the beginning. In the first place would he have adopted a comparatively low voltage for works scattered over a considerable area and involving considerable power, and secondly would he have adopted continuous current? It was noticeable that a large number of the motors in this installation were out of doors, and it struck the speaker that probably polyphase motors would have been less liable to injury and more applicable, and he would like to hear some one else's opinion as to whether a polyphase installation would not have met the case better. Another point which had not been touched upon was the subdivision of the power. He thought that the avoidance, to a great extent, of shafting and belting in such works was very important. He noted that Mr. Wraith used separate motors for the larger lathes, and thought that was a step in the right direction. The other tools were driven probably by long lengths of shafting, and shafting in such establishments was not always put up as well as it might be, nor maintained in good order, and frequently a large proportion of the total power developed was absorbed in driving shafting and belts. He could quite endorse what had been said about belt-driving motors. With regard to the troubles that occur with con-

tinuous-current motors, vibration due to bad gearing was frequently the cause of breakdown. He had recently had under his observation two or three such cases. A motor was sent by his firm to a colliery in Lancashire, and shortly after being set to work, the wires at the connection of the commutator had broken off in a mysterious way. These were mended, and the motor was severely tested in the works with a great overload, and yet when it was returned the wires broke off again. The running of the machinery caused a good deal of noise which made it very difficult to detect anything from sound, but it was noticed that the pinion which had been put on the motor was shrouded, and that the tooth wheel which it worked just caught the shrouds and caused excessive jarring on the motor. The shrouds were turned off, and the wires never broke again. It was obvious that the vibration due to the teeth catching the shrouds had broken the wires. Another instance was that of a motor that had been working for several months, but this had bevelled wheels. Suddenly the wires began to break, and it turned out that new bevelled wheels had been fitted which worked deeper into gear, and caused excessive vibration. Mr. Churton.

Mr. W. Emmott said he had had armatures which behaved in a similar manner to those referred to, and had got over the difficulty by putting more sections in. He thought at the time that that was the cause of them breaking, but he now thought there were a lot of other reasons. With reference to the coal costs, he thought they were a very good advertisement, and would be appreciated. He thought it would have paid these people to put their own power gas plant in, as they would then have had a fuel bill of 0·2 instead of a coal bill of 0·4. Mr. Emmott.

Mr. H. O. Wraith, in his reply, said that his critics favoured solid trolley wires in place of stranded wires. The whole reason for putting in the stranded wires was the one given, that if a solid trolley wire is practically burnt through by a short circuit it is very rarely it can be patched up, and if you have a stranded conductor it is easier to do so. He had, however, lately seen a much better idea for crane currents going along the shop, and that is steel angle-bars run on insulating brackets, thus doing away with trolley wires altogether, with flat shoes pressed against it, to communicate the current. Mr. Wraith.

Mr. Rosling said that he considered the motors of the shipyard were rather oversized, and he thought he was right in these particular cases.

Perhaps the paper was rather confusing. The fourth generator set was not put in until the full load was as much as three could carry and the load was still increasing. The system of the whole plant is not yet complete, and is being continually added to. At the time at which these remarks apply there were only three sets installed, but the fourth set has been put down for additional work, and is not entirely a spare set.

With reference to the point that in a case of this sort, where owners wished to convert their works gradually, that the central stations were an advantage, Messrs. Doxford for their new shipyard are taking at the present time the whole of the current they require from the Corporation, and of course they are taking stand-by current in case their generating plant breaks down. I think their reason for that was not so much that the Corporation current was an advantage as that they had not room

Mr. Wraith. or convenience to build a power station of the size that they would ultimately require. At the same time the question of cost per unit generated is in favour of the private plant.

With reference to the time load for starting the machines being short, he was afraid that if they had to wait a minute every time a lot of time would be lost. The electric drills he mentioned were hand drills, and for drills of a larger size there is bound to be a truck of some sort with flexible shafts. He was comparing them with pneumatic hand tools. After trying the liquid starters he came to the conclusion that they were the best under the particular circumstances and easier to use. With reference to Mr. Churton's request as to what voltage he would adopt for an installation of this kind, he thought that for a place with dimensions of anything from a ¼ to ½ a mile square 440 or 500 volts was better than the 220, with a three-wire system for lighting.

He did not want to raise the question as to continuous or polyphase motors. He took the equipment of that particular engine works and shipyard as a basis, but he knew a great many shipyards had three-phase installation working satisfactorily, and he thought it every bit as good as continuous, if not better. In works of this description, employing a large number of cranes, the difficulty of regulating polyphase motors on them would probably out-balance the advantage of having fewer working parts on the motors in the works. There were no very long lengths of shafting. Most of the machines were running off shafting, with the exception of the larger ones in the engine works, boring machines, etc., so that all the tools were not driven by lines of shafting. Regarding the breaking of the commutator arms, he cited a similar instance, but put the blame on the commutator arms, which were cast ones, cast in with the commutator segment, not very good practice. With reference to the chairman's remarks *re* Mond gas, the author intended to convey the impression that in cases where the size of the plant justified it, it would be a very good thing to instal a special gas plant. It was open to doubt, in this particular case, whether a Mond gas plant was an advantage, as steam was required for steam hammers and various other purposes. He had advocated a Mond gas plant for the works in question, but had proposed to use the gas for firing the boilers, as well as for heating furnaces, etc., but not to drive the dynamos by gas engines. In this way the cost of firing could have been much reduced, without the added capital cost of gas engines to replace the existing steam dynamo engines.

BIRMINGHAM LOCAL SECTION.

SOME USES OF THE OSCILLOGRAPH.

By D. K. MORRIS, Associate Member, and J. K. CATTERSON-SMITH, Student.

(*Read at Meeting of Section Jan.* 27, 1904.)

1.—THE RECORDING OF MAGNETISATION CURVES OF TRANSFORMERS DURING WORKING.

The registration of the behaviour of the magnetic cores of transformers when working on the mains is a matter of considerable practical interest, but has hitherto proved a difficult problem from the experimental point of view. There is the well-known method of obtaining the loop by comparing the waves of current and E.M.F. at no load; then, the Braun vacuum tube has been applied so as to record the instantaneous magnetisation curves; and lastly, the curve of magnetisation of transformers has been obtained by slowly varying the magnetising current at such a rate that the induced electromotive force was kept constant throughout the change.

The method described in the following note is an application of the double oscillograph—that used was one of the Duddell pattern; and the device consists in passing through one of the oscillograph strips a current proportional to the magnetising force; and, through the other, a current proportional to the flux density; and finally, in causing a beam of light to be so reflected, first from the one oscillograph mirror and then from the other, that the final reflected ray shall partake of both vibrations as co-ordinates in the usual manner of **B-H** curves.

Optical Arrangements.—The synchronous motor and mirror commonly used with the oscillograph was removed, and its place taken by a frame holding a right-angle prism, P, and a silvered lens, A (acting as a concave mirror). The following figures (Figs. 1 and 2) represent the arrangement, the angles being slightly exaggerated for the sake of clearness.

No lantern condenser was used. The beam of light from an electric arc passed through a pin-hole, G, and after reflection from M_1 partook of a horizontal vibration proportional to **B** (as shown later). After passage through the right-angle prism P, which was placed in the position indicated, namely, with its largest face in a plane parallel to the beam of light but at 45° to the plane containing the base of the oscillograph, the horizontal vibrations were transposed by the refractions and reflection indicated into vibrations in a vertical plane. The beam, thus vibrating, was then received on the concave mirror A,

which was of sufficient size to take the whole of the vertical streak of light ($1\frac{1}{2}$ in. long) described by the vibrating beam. The focal length of this mirror A was such that the image of the oscillograph mirror M_1 could be thrown exactly on to M_2. But this mirror M_2 was vibrating with the magnetising force, **H**. While, therefore, the beam of light which converged on M_2 was vibrating vertically with **B**, the beam reflected from it possessed in addition a horizontal vibration proportional to **H**. A plane fixed mirror F at 45° (Fig. 2) was found convenient in order to bring the resultant beam out of the way of the other paths of light.

It would be possible, of course, to construct a double oscillograph with the axes of vibration at right angles, somewhat after the manner of the Ewing curve-tracer, so that the above optical arrangement would be unnecessary.

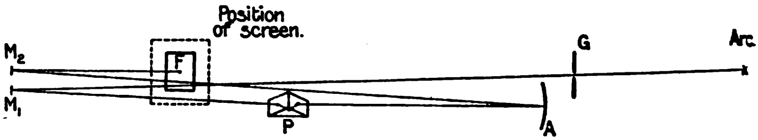


FIG 1.—Plan.

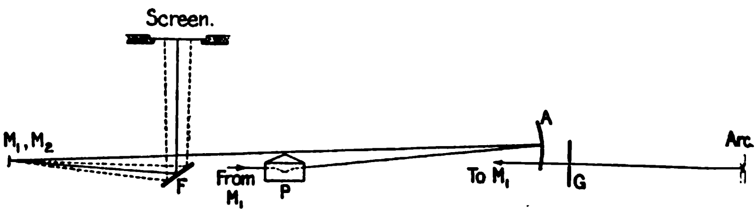


FIG 2.—Side Elevation.

FIGS. 1 and 2.—Optical Arrangement for **B-H** Curves.

Scale : $\frac{1}{2}$ full size.

Electrical Connections.—The no-load current of a transformer is a measure of the magnetising force applied to the core, and except for the demagnetising action of the eddy currents it measures the value of **H** for the core. The principle of the method employed in obtaining a current which shall be proportional to the induction density, **B**, is extremely simple. A large coil having no iron core, and of inductance and resistance as nearly as may be comparable with that of the transformer at no load is placed in parallel with the transformer winding.*

* Should this voltage be excessive, it is practicable without sensible error to transform it down, and so allow the use of a smaller "air" coil.

Assuming r_1 and r_2 to represent respectively the resistance of the transformer and "air-coil" circuits (in which the varying currents c_1 and c_2 are flowing), and writing L_2 for the inductance of the latter circuit, then the following equation must hold at every instant—

$$r_1 c_1 + \frac{ns}{10^8} \frac{dB}{dt} = r_2 c_2 + L_2 \frac{dc_2}{dt}$$

where n is the number of turns, and s the sectional area of the iron in the transformer core.

The first term of each side of this equation is a vector approximately at right angles in phase to the vector representing the second term, so that if $r_1 c_1 = r_2 c_2$, then c_2 is proportional to **B**, since they both vary periodically. Owing, however, to the irregular form of c_1, it is necessary not only to have the ohmic drops equal, but that both should be small relative to the second terms; otherwise the magnetisation curve obtained requires an irregular correction, which, though not impossible to estimate, is very troublesome.

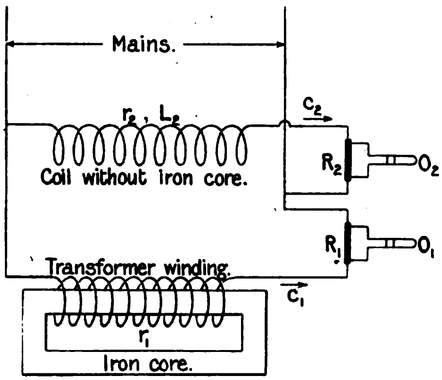


FIG. 3.—Diagram of Connections.

The condition, therefore, for successful **B-H** curves is that the ohmic drop in both circuits shall be equal and also small in amount.

The electrical connections necessary for obtaining magnetisation curves in this way are shown in Fig. 3. O_1 and O_2 represent the two oscillograph strips, and the resistances R_1 and R_2 are chosen so as to give suitable magnitude to the co-ordinates of the resulting curve.

This method was employed to obtain the hysteresis loop of the core of a 1½ k.w. Burnand transformer. In the actual experiment the secondary was unloaded, and the primary was working at normal voltage and frequency (70 volts, 40 ∿) for this transformer.

A photographic trace of the magnetisation curve for this transformer is shown in Fig. 4. The zero lines were obtained photographically by switching off the current first from one and then from the other oscillograph strip.

Special care has not been taken up to the present to secure the conditions mentioned above as necessary for the greatest accuracy in the **B-H** curves; but it is interesting to notice that as far as present observations go, all the magnetisation curves appear sharply angular at the turning-point; not rounded off at the corners as has been frequently averred to be the result of eddy currents. Experiments on the no-load loss of this transformer at varying frequencies indicate that the eddy-current loss at 40 $\sim$ is about 15 per cent. of the total no-load loss.

The method is applicable to the determination of eddy currents, for without altering the apparatus, the same values of **B** can be obtained (taking account of the ratio of the impedance of the two circuits) from a direct-current supply, and can be varied cyclically. The reduced values of **H** will then give at once the demagnetising action of the eddy currents (provided there are no time effects in the magnetisation).

The method of superposing the vibrations of two oscillograph strips in planes at angles is also applicable to the estimation of small power-factors, since a straight line can only be obtained as the resultant vibration when the two waves in these strips are exactly in phase. This straight line is set at 45° to the axes when the vibrations have equal amplitudes. Any departure from the condition as regards phase results in an ellipse more or less elongated, the ratio between whose axes is a measure of the power-factor. It should be noted that the **B-H** curve in Fig. 4 is itself an example of such an ellipse;—very much distorted from the elliptical form on account of the varying angle of lag caused by hysteresis.

The authors hope to give the results of measurements with the above method at a later date.

2.—Armature Currents in a Shunt-wound Motor, and in a Rotary Converter under Varying Conditions of Load.

The experiments of which the following are illustrations, were made with a 110-volt Westinghouse 7½-k.w. converter, used first as a shunt motor and then loaded on the alternating-current side. A special attachment consisting of three heavy copper slip-rings suitably insulated was supported on a frame bolted on to the revolving part. The armature winding, which was of the ordinary four-pole series type, with only two paths for the current to flow from positive to negative brushes, was cut at one place on the side furthest from the commutator and the exposed ends led by stout short connections to two of the slip-rings. From one of these slip-rings a No. 26 silk-covered wire was led as closely as possible along the coil which had been cut, threading it under the binding wire and returning in a similar way to a third slip-ring. Thus, when the brushes on slip-rings 1 and 2 were short-circuited by a suitable low-resistance shunt, the potential across this shunt was a measure of the current flowing in one-half of the armature; and the potential between the second and third slip-rings was directly proportional to the voltage in the armature coil. A Duddell oscillograph of the double high-frequency pattern was arranged to measure these two potentials.

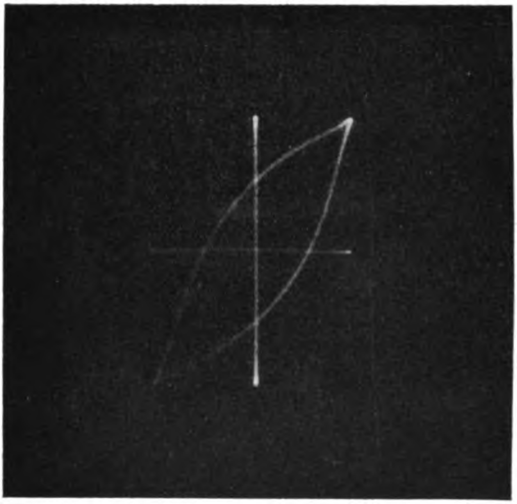


FIG. 4.—Hysteresis Loop of Transformer taken while working at 40 ∿.

Scales (approximate):—Horizontal: 1 in. = 1 amp. of no-load current.
Vertical: 1 in. = 4,000 lines per cm². in core

It should be mentioned that practical conditions of running were not quite realised in the experiments, for the current flowing between the first two slip-rings, instead of being exactly one-half of the whole external current supplied to the armature, was less than this amount by about 5 per cent. This arose chiefly from the necessary resistance of the measuring shunt connecting brushes 1 and 2; and also was caused to some extent by the resistance of these two brush contacts. The two

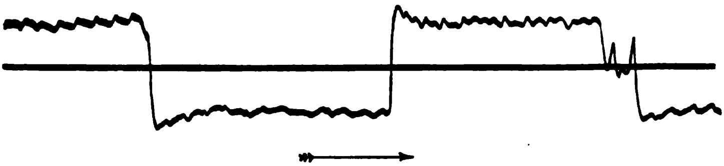


FIG. 5.—Internal Armature Current of Unloaded Shunt Motor running at 1,200 r.p.m. Brushes in neutral position.

Scales (approximate) :—Horizontal : 1 in. = $\frac{1}{160}$ of a second.
Vertical : 1 in. = 20 amp. in one conductor.

halves of the armature winding were in this way slightly unsymmetrica as regards resistance. The normal armature resistance of this machine is 0·035 ohm (viz., two halves each 0·07 ohm in parallel), while the resistance of the inserted shunt was about 0·03 ohm.

When the brushes are carefully set, the current-wave takes the form shown in Fig. 5. The irregularities due to the armature teeth are

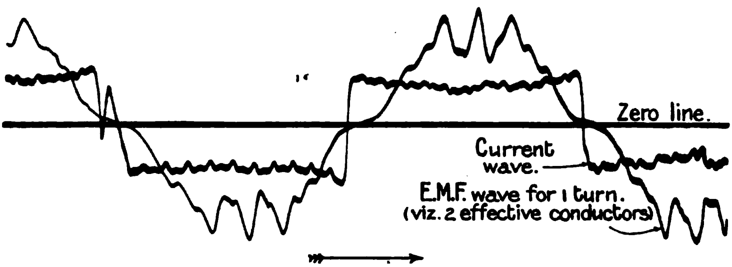


FIG. 6.—E.M.F. and Current Curves of Unloaded Shunt Motor.

Scales (approximate) :—Horizontal : 1 in. = $\frac{1}{160}$ of a second.
Vertical : { 1 in. = 20 amps. in one conductor.
1 in. = 6·5 volts.

almost absent, and the commutation occurs promptly. The machine has four carbon brushes—a single broad brush at each point of contact, and not two or three smaller brushes as is common in many types of motor. The result of imperfect bedding of one of the brushes is shown on the right. A similar effect is shown in Fig. 7, on the left. The complete double reversal of current takes place in $\frac{1}{2}$ a revolution, since the machine is 4-polar, and as the speed during this and the following

experiments was 1,200 r.p.m. this occupied $\frac{1}{40}$th of a second, and the scale of the time-base of these curves is almost exactly $1'' = \frac{1}{100}$ of a second.

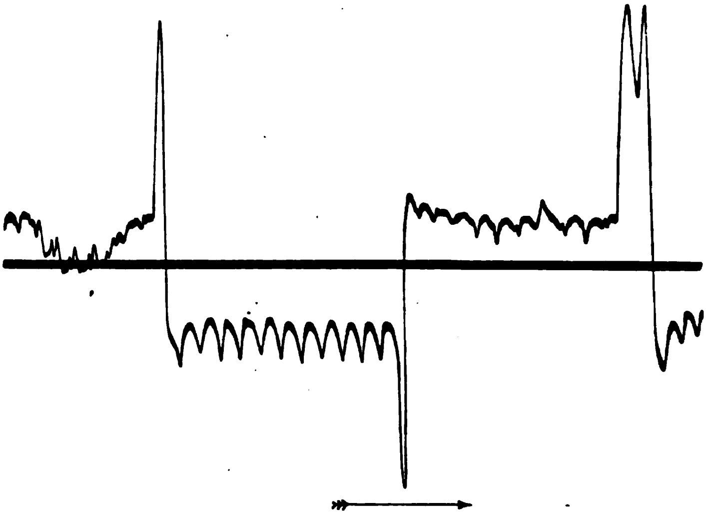


FIG. 7.—Brushes shifted forward in direction of rotation

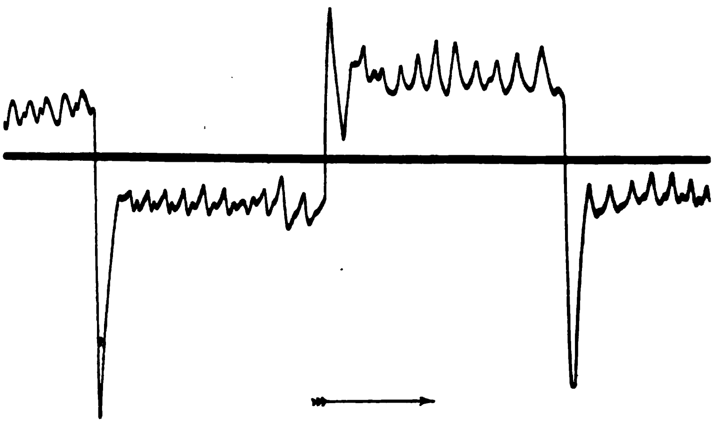


FIG. 8.—Brushes shifted backward.

FIGS. 7 and 8.—Internal Armature Current in Unloaded Shunt Motor with Brushes incorrectly placed. (To compare with Fig. 5.)

Scales as in Fig. 5.

In Fig. 6 the current-wave is shown under the same conditions as before, and, in addition, the variations of E.M.F. are given for a single

turn of an armature coil. The peaked form of this wave is due to the presence of damping pole-pieces formed of a copper casting divided into four bars. The nature of the magnetic field during commutation can be clearly seen.

The armature of the machine used has 47 slots, and the auxiliary turn of wire between slip-rings 2 and 3 which furnished the E.M.F. curve in Fig. 6 embraced 10 teeth of the armature. There are 47 segments on the commutator. An armature coil of two turns can be traced as follows :—From segment 1 through slot 7 and back by slot 17, then through slot 8 and back by slot 18 to segment 25. A similar coil of two turns connects this segment to segment No. 2. The E.M.F. of an armature coil is exactly twice that shown in the above curve, while the voltage between adjacent commutator segments is about four times the ordinates of this E.M.F. wave.

Figs. 7 and 8 show the effect of having the brushes in a false position. If the brushes are shifted forward in the direction of rotation, the induced E.M.F. (which in a motor is normally opposed to the direction of flow of current) will already have reversed by the time that the brush short-circuits a coil, and will therefore coincide with the direction of current previously flowing. In Fig. 7, the heavy short-circuit current is seen to occur previous to reversal ; while in Fig. 8, for which the brushes were shifted backwards, the short-circuit current is in the opposite direction and occurs just after the current reverses.

The vibrating mirror used for drawing out the oscillograph traces so as to give the horizontal time-base was actuated by a synchronous motor worked by a small alternating current taken from two of the converter slip-rings. The phase of this depended on the relative position of the points of junction of these rings to the armature winding and that of the pole-faces. So that the relative phases of Figs. 7 and 8 as compared with Fig. 5 give a measure of the amount of shift of the brushes forward or backward—causing later or earlier commutation respectively.

The irregularity of the current due to the armature teeth is very marked, so that the 11 or 12 complete notches per pole can be easily counted.

The curves in Figs. 7 and 8 show a difference between the positive and negative current-wave, according to whether the brushes are shifted forward or backward. The cause of this is not quite clear, but suggests unsymmetry in the position of the brushes.

Armature Currents in a Rotary Converter.—The converter was run from the D.C. side, and the following three figures (9 to 11) show very clearly the way in which the armature currents which normally were as in Fig. 5 become modified with increasing alternating load.

It will be seen how the above figures 9 to 11 are the result of the superpositions of an A.C. wave upon the current-wave of Fig. 5. The phase of this alternating wave depends upon the points where the A.C. slip-rings make connection with the armature winding. The three-phase slip-ring connections were of course nearly 120° of a magnetic revolution apart, and the coil whose current is recorded was actually

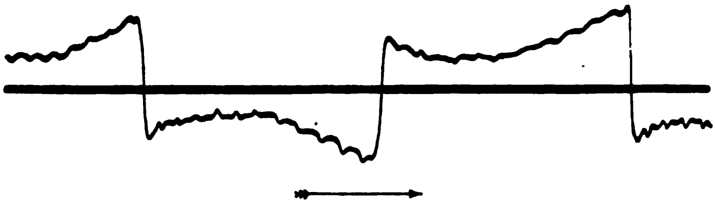


FIG. 9.—Internal Armature Current of Converter run from 110-volt D.C. Mains and loaded on A.C. slip-rings as follows: 10 amperes at 75 volts and unit power-factor.

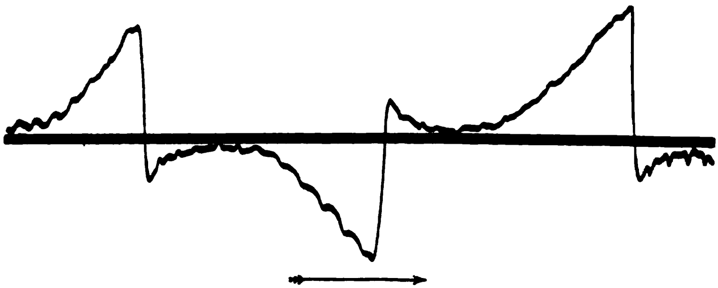


FIG. 10.—Same as Fig. 9, but with greater A.C. load of 18 amperes from same slip-rings, and unit power-factor.

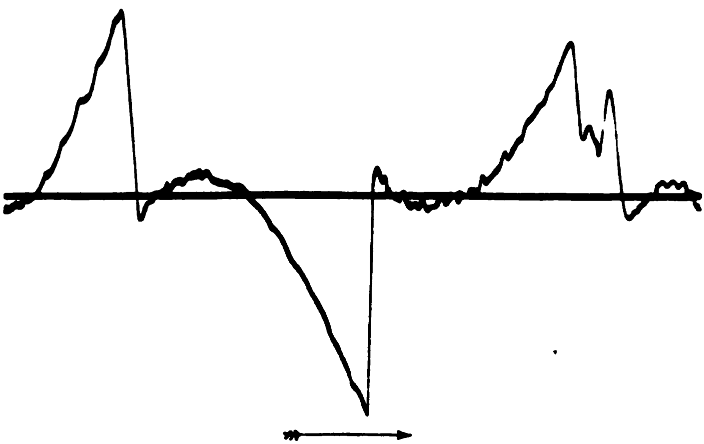


FIG. 11.—Still greater A.C. load of 27 amperes at about 70 volts and unit power-factor.

FIGS. 9 to 11.—Armature Currents in a Rotary Converter furnishing Alternating Current at 40 Periods.

Scales of current and time as in Fig. 5.

situate between these slip-ring connectors about ¼ of the way (2 slots) from one to the other.

In conclusion, we would like to express our indebtedness to Messrs. F. B. Carmichael, A. W. Lambourne, and the departmental assistant, Mr. Bird, without whose energetic assistance we could not have given this demonstration.

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BIRMINGHAM LOCAL SECTION.

LOCALISATION OF FAULTS ON LOW-TENSION NETWORKS.

By W. E. GROVES, Associate Member.

(*Paper read March* 16, 1904.)

It is perhaps fortunate that, in contrast with some other public supplies, that of electricity requires for its successful operation that faults and leakages be immediately remedied. Any laxity in maintaining the insulation is sooner or later fraught with disaster. It is also fortunate that such leakages or faults can be readily detected, and that their localisation and elimination are a comparatively simple matter. The remarks which follow refer particularly to a three-wire low-tension network, with the neutral earthed at the generating station, or sub-station, through a resistance of 2 ohms.

The rapidity and ease with which a fault can be localised depend in a great measure on the arrangement of the networks, and still more on the completeness of the plans and details kept.

The more closely a network is "netted," the more troublesome it is to localise faults, and from this point of view it is very desirable that each feeder should have its own defined network, and be only linked to other similar networks where necessary for balancing and equalising purposes. All possible points of junction between the networks of the various feeders should be labelled on the mains plans and distinguished in the boxes by some particular type of fitting.

There have been various opinions expressed as to the degree of fusing of networks that should be resorted to. In the writer's opinion it is desirable, in addition to the feeder fuses in the station, to fuse at all points where it is found advisable to effect a junction between the networks supplied by different feeders, and generally *at these points only*

The obvious danger of connecting two or more feeders through a distributor without fusing is that in the event of a short circuit, or bad fault, the faulty feeder fuse in the station may blow, and the "short" be

fed through a small distributor of sufficient resistance to prevent another heavy feeder fuse from blowing immediately, but carrying enough current to badly overheat and destroy it.

The fuses at the inter-connecting points can be comparatively light, because if the system is properly arranged, the balancing currents will be small.

During summer it is usually no disadvantage to work with many of the linking points open, which provides an excellent opportunity for overhauling the various networks. When a link is closed it should be noted in a book, or on a card provided for the purpose in the office, in order that there may be no delay or hesitation if it is necessary to sever the various feeder networks for localising a fault.

Although the convenience of independent feeding for fault-localisation is very great, the efficiency and balance of the system must be the first consideration, and the fuse links inserted wherever any advantage can be obtained by inter-connection.

Fusing of the linking points gives no cause for anxiety, as there is little chance of the fuses blowing except when they are fulfilling their proper functions, and if they should be severed from any other cause nothing worse can occur than a temporary want of balance. The neutrals, at points where fuses are inserted on the outers, will of course be connected up solid. By the use of interchangeable blocks it is possible to fuse any line which may become an object of suspicion.

A junction box, with interchangeable blocks of three types, is described in Appendix I.

As the space for fusing in a junction box is necessarily limited, unless the box be of cumbrous dimensions, it is perhaps possible that in aggravated cases the fuse arc might spread; but even if this did occur, it would be a small matter, and it would "save the situation," for if you can start an arc, the sudden drop in volts due to the "short" would break the arc, and the faulty line would be freed.

It is conceivable that more extinctions would result from the blowing of distributor fuses on slight provocation than from the very rare blowing of a feeder fuse. If the faulty feeder is automatically isolated by means of link fuses, it should not be difficult to locate and disconnect the "shorted" line, an intimate knowledge of the network by means of plans and details being of the first importance. It is a simple matter to draw the various connecting bolts, and try with portable switch and fuse when the line is clear. A means of connecting this switch should be provided in the junction boxes.

The subject of short circuits is so closely related to the question of distributor fuses, and the lay-out of the system generally, that "shorts" occupy first attention, but the maintenance of the insulation in such a manner as to protect the system from faults that may develop into "shorts" is of the greatest importance. On the soundness of the insulation depends the "safety" of the consumer and the reliability of supply. In the discussion of Mr. A. M. Taylor's recent paper, "Network Tests and Station Earthing," reference was made to various tests. The desire to make this paper as complete as possible must be the excuse for the repetition of remarks made on that occasion.

The tests and trials the writer has found convenient are as follows :—

(*a*) Observance of reading of recording ammeter permanently connecting the neutral to earth through a low resistance.
(*b*) Joint insulation test by "Russell's Method."
(*c*) Checking polarity of fault by observance of feeder ammeter when "flashed."
(*d*) Detection of faulty feeder by "flashing."
(*e*) Partial localisation by means of "transferring."
(*f*) Localisation by disconnection to shortest length.
(*g*) Final localisation by induction method.

The avoidance of interruption of supply in any degree is of great consideration, and these tests and trials are selected with that object in view.

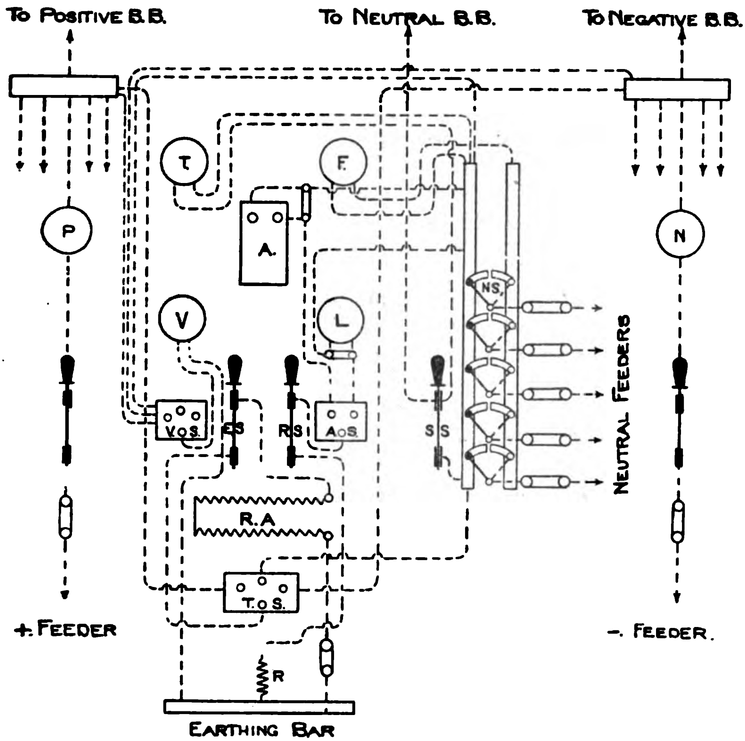


Fig. 1.

Fig. 1 shows an arrangement of panels for the ready performance of tests (*a*) to (*e*) inclusive. The somewhat elaborate array of neutral switches is necessary to avoid the inadvertent disconnection of a neutral cable when testing.*

* These switches would not be required if an ammeter shunt were provided on each feeder neutral, when a multi-way switch could be used.

The connections of the panels will be easily traced, and where necessary the functions of the various instruments are described in what follows:—

(*a*) *Recording Ammeter.* The reading and recording of this instrument is so far useful that it shows any alteration in the state of the insulation of the mains, and if the reading is considerable, renders test (*b*) necessary. Its great weakness lies, as has been many times pointed out, in its readings being differential, and not less in the fact that it may be shunted by a neutral fault. These qualities render it wholly unreliable as an indicator of the state of the insulation of the mains. It is sometimes most useful in showing the nature of a fault (such as a defective motor armature by oscillations of the needle), also the records frequently indicate, by the time of the arrival and disappearance of a fault, whether or not it is controlled by a consumer's switch.

If the recording ammeter is reading Zero it indicates one of three conditions: (1) that the insulation is absolutely sound, (2) the outers are equally unsound, or (3) the instrument is shunted by a neutral fault. The first case is an imaginary one—in stations of any size; the second of very infrequent occurrence, and the last always to be suspected.

(*b*) *Russell's Test.*—This is most convenient for a rapid and frequent test. The formula (*vide* Mr. Russell's communication, *Journal*, vol. 30, p. 326) is $F = \frac{V2 - V2'}{c} = \frac{V2}{c} - R$.

Referring to Fig. 1, R is the resistance in series with the recording ammeter A (say 2 ohms), so that the test resolves itself into the reading of C on the ammeter L in series with or substituted for A at the time of testing, and a momentary opening of the switch RS to read V2 on the voltmeter V. For moderately high resistances the value of R may be ignored. V should theoretically be of infinite resistance, *i.e.* electrostatic, but the results of this test are quite sufficiently accurate if any high-resistance voltmeter is taken.

The writer is experimenting with a combined instrument which, if satisfactory, would replace V and L on the panel Fig. 1.

The object of this instrument is to read F directly on an ohm scale when RS is momentarily opened. A diagram and description of the suggested arrangement is given in Appendix III.

If the recording ammeter fails to notify any leakage, and the test (*b*) indicates that the insulation is "down," it is fairly safe to assume that the neutral is at fault, although occasionally a balance may occur. Under these conditions V2 will be small and RS may be left open while the rough tests (*c*) and (*d*) are made. The opening of the switch RS avoids heavy local currents through R and bad sparking at the switches.

(*c*) *Checking Polarity of Fault by "Flashing."*—A central zero ammeter T is provided, which can be cut in to take the total neutral current by opening the switch SS. Watching this instrument until a fairly steady deflection is shown, either of the outers may be connected to earth through the adjustable resistance RA by means of the

switches TS and ES. If the neutral is faulty a "kick" will occur on T when ES is closed. It is sometimes necessary to make this trial when most of the motors on circuit are shut down on account of the unsteadiness of the deflection on T. In the case of a balanced fault the neutral ammeter T will be unaffected by this trial, the switch RS being open, and the faulty feeder will be indicated by "kicking" of one of the ammeters P, N, on the opposite side to that earthed.

(*d*) *Detection of Faulty Feeder.*—If the last test has proved that the neutral is unsound an ammeter F may be cut into each feeder separately by means of the switches NS (or a multi-way switch if ammeter shunts are fixed in the neutrals), and the last test repeated until the faulty feeder is detected.

If a considerable fault is shown on A the switch RS may be momentarily broken while close observation is made of the instruments P and N. Obviously, a heavy balanced leak is in the nature of a short circuit, and being beyond the control of R, makes itself sufficiently apparent on P and N. In extreme cases of this kind it may be necessary to cut out the faulty pole of one feeder while the fault on the other pole is being eliminated; but if the insulation generally is kept under close observation, this double fault should be of very rare occurrence.

(*e*) *Partial Localisation by Transference.*—It is usually the case that a junction can be made between the distributors branching from the various feeders (preferably through fuses, as mentioned above). By transferring the distributors from one feeder to another, and momentarily earthing one of the outer wires, if the neutral is faulty, or flashing the switch RS if an outer is "down," the fault may be very readily localised to the shortest length the arrangement of the network will permit. So far consumers have in no way been interfered with unless operations may have blown the fuse of a faulty internal circuit.

The earthing of either pole through an adjustable resistance RA by means of the switches TS and ES is of great service in blowing out faults controlled by small-circuit fuses on consumer's premises. It may occur that the neutral is "held down" by a fault which may disappear on a very slight earthing of one of the outers. The consumer will have the fuse replaced, and it may be necessary to repeat the process until he thinks it worth while to investigate the cause of his trouble. It is probable that in this case a few lamps on the faulty circuit will be burnt up; it is the penalty of having a fault.

Of course if, in addition to the above-mentioned fault, a considerable fault on either outer develops, it will automatically affect this process; but should such a fault be absent, a defective single-light circuit may spoil the insulation records for days. There would be little satisfaction in finding, after a tedious search, a fault controlled by a 5-ampere fuse. The writer is assuming that there are no neutral fuses in the purely 3-wire circuits, or that they are sufficiently heavy to be unaffected by such slight earthing as has been mentioned.

(*f*) *Localisation by Disconnection.*—If disconnection can be resorted to without inconvenience to consumers, it may save the time and trouble of carrying test (*e*) to its extreme limits, the transfer method meaning

frequent journeys to the station to study the feeder ammeter or time in fixing up instruments at the feeding points. If arrangements can be made for disconnection, tests may be made by means of lamps or instruments. If the fault be on either outer the volts between neutral and earth will be raised. Having connected up the lamp or voltmeter between neutral and earth at the nearest network box, the various lines or services are disconnected until the volts drop. When the fault is neutral (the earthing switch RS at the station being open), an earth connection may be made through a switch and fuse at the junction box where the test is being carried out, the switch being

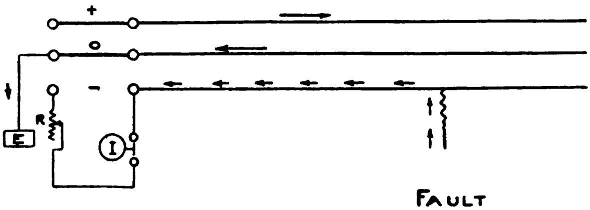


FIG. 2.

opened after each disconnection until the faulty line is detected by a rise of volts on an instrument connected between neutral and earth, when the faulty line is cut off.

As an alternative to the last trial, a lamp may be connected between either live outer and the faulty neutral, the latter and other outer being disconnected. The faulty line being at or near earth potential, the lamp will glow until the fault is made dead. It is well to make trials at the station before carrying out these rough street tests, in order that the results may be correctly interpreted.

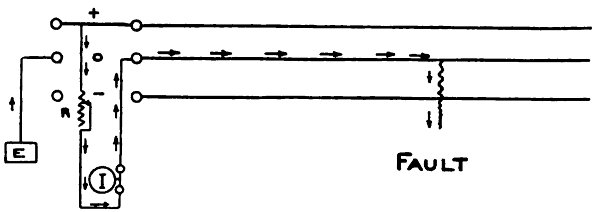


FIG. 3.

(*g*) *Final Localisation by Induction Method.*—The tests described above having failed to indicate the exact position of the fault, final localisation may be made by means of an interrupter and induction coil.

This generally well-known method consists in putting an alternating or interrupted current through the faulty cable, the circuit being completed through earth. A coil in circuit with which is a telephone receiver is taken over the route of the faulty cable, starting from the point from which the testing current is supplied.

In a successful test the receiver beats steadily until the point of the fault is reached, when the beat dies away more or less suddenly, owing to the test current going to ground.

A description of an interrupter designed by the writer, and also of a convenient form of coil, will be found in Appendix II..

Figs. 2 to 6 represent various methods of connecting the interrupter. The small arrows indicate the interrupted earth current, large arrows the supply current, and double-headed arrows the fault current.

Fig. 2 represents the simplest case where the faulty line can be disconnected, and the interrupter inserted in series with the fault—the fault being on one of the outers.

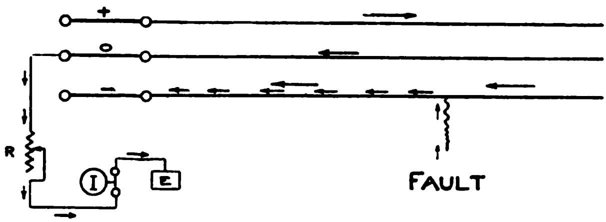


FIG. 4.

Fig. 3 shows a method of localising a fault in a neutral. The faulty neutral and one outer are disconnected, and the interrupter connected between the "live" outer and the faulty line.

In Fig. 4 the neutral is not "permanently" earthed, or the fault is so bad that the removal of the "permanent" earth connection has no

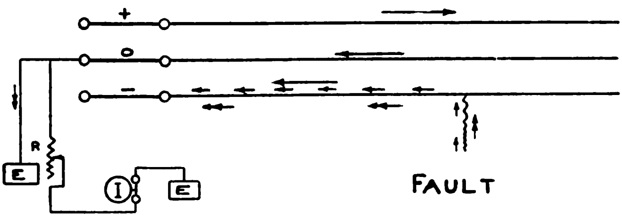


FIG. 5.

appreciable effect on the pressure between neutral and earth. No interruption of supply is necessary in this case, the pulsating current being superimposed on the supply current.

If the coupling is as shown in Fig. 5, no interruption of supply is necessitated, the pulsating current being superimposed on both the supply and the fault current.

When iron ducts are in use or the cables are metal-covered, contact between the ducts or armour and a gas or other metal pipe sometimes leads to false indications, particularly if the surrounding soil be dry.

The effect is shown in Fig. 6. The fault being at B (*i.e.* the contact between conductor and metal cover), the current takes the lowest resistance path to earth at the point of contact with the pipe returning

upon itself. In this case the telephone will cease beating at A, the effect of the pulsating current between that point and B being neutralised. The ground is opened at A and the pipe contact removed when, unless there are other similar contacts, a true indication is given. Proximity but not actual contact has the same effect in a less degree.

The coil is therefore useful in indicating where the cable ducts and other pipes are too close together, but proper precautions should be taken to avoid such contiguity when the cables are laid.

The writer has found the induction method of fault localisation very satisfactory. It is more definite in its indications at one time than another, and nearness of other mains or pipes running parallel is an embarrassment. At the same time the exact position of a fault has been indicated on a cable surrounded by a large number of live cables, and where a satisfactory result was to be least anticipated. An explanation of this and occasional converse cases would be of the greatest interest. Complete failure with single conductor cables is, in the writer's experience, almost unknown.

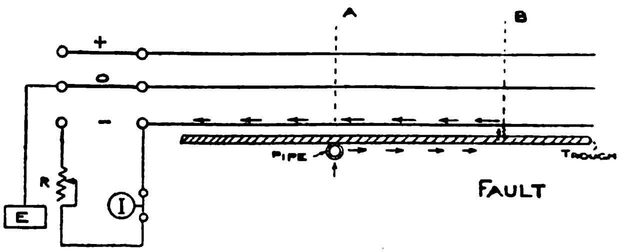


FIG. 6.

It is well, when a faulty line is localised, to thoroughly inspect the surface and open up any suspicious points where there have been recent excavations for any work in connection with the laying of other mains, pipes, or for executing road repairs or alterations. Much time and labour may be often saved in this way.

If the coil indicate a certain point it should be ascertained whether a service or T joint is taken off at such point, and, if there is, the coil will, of course, be taken along the branch line.

If the telephone beat "tapers off," the fault is to be looked for where the "taper" commences.

It is of the greatest importance that particular care be taken to note any deviations in the cables when the coil is being taken over the route. Dips in the main at road-crossings, etc., are to be carefully taken account of.

It is of course desirable to have the coil as light as possible; consequently the beat will be no louder than is necessary.

As the distance from the cable under test affects the beat of the receiver, a deviation (which should certainly be found on the mains plans) has naturally the same effect on the telephone, if the coil does not follow it, as a true indication when the coil is over the fault.

The loudest beat is not always the best. It is often accentuated by induction in parallel conducting media. It is sometimes necessary to earth artificially all mains and armourings running parallel to get satisfactory indications.

There is no rule, and it is always well to try the test without earthing precautions in the first instance. It is as likely to succeed as not, and, if successful, time and labour are saved.

The localisation of faults by the exploring coil when armoured or lead-covered cables are employed is generally more troublesome than with single-core cables without metallic sheathing, by reason of the misleading effects of induction before referred to.

If a fault is partially localised on either outer, but cannot be eliminated before dark, the main may be cross-coupled in the nearest junction box, making the faulty cable neutral. This should preferably be done through a fuse, in order that the recording ammeter and earth resistance may not be cut out in the event of a bad fault turning up on either outer.

There is risk of breaking lamps on the crossed circuit, but it is better to take this risk for a few hours than put many consumers in darkness. The meters of some consumers will also be temporarily reversed, but extinction is always the greatest evil, and the reputation of the supply business is of more value than the units unrecorded or cancelled by the meters.

Exception may be taken to the rather free manipulation of the earthing switch. Although it should be left alone as far as possible, and always controlled by a spring to prevent its being inadvertently left open, it should never be allowed to interfere with the ready detection and elimination of faults. It is also essential for the continuity of supply that the earth connection should be made through a resistance, as mentioned above, for reasons too obvious to need repetition.

The frequent checking of the soundness of the neutral is the key to the proper maintenance of insulation. Neutral faults, not being self-apparent, accumulate if means are not taken to detect them until the recording ammeter and resistance are effectually shunted. This would create a "fools' paradise," to be followed sooner or later by a "rude awakening."

The various localisation tests, such as are fully described in Raphael's "Localisation of Faults," have not been touched on—it would be difficult to elaborate on them. They are excellent in their way, but there are practical difficulties in the use of sensitive instruments on supply mains, and the writer prefers to localise leakage faults by means of the exploring coil, and thinks it will generally be found the most expeditious method, except sometimes when armoured or lead-covered cables are under test. In the event of a "short" which has not "grounded" some text-book method of localisation must be employed.

In concluding this account of rough and ready, but practical methods of fault detection and removal, the writer ventures to hope the subject may be considered of sufficient importance and general interest to provide material for an interesting discussion, to which he looks for much information and instruction.

APPENDIX I.

Fig. 7 shows a network box fitted with three types of blocks, as mentioned above, for (1) connecting solid, (2) fusing, or (3) isolating distributors or branches. In the illustration the distributors coming from Feeder 1 are shown connected solid by means of the block B. The distributor from Feeder 2 is connected by a fuse block A, and that

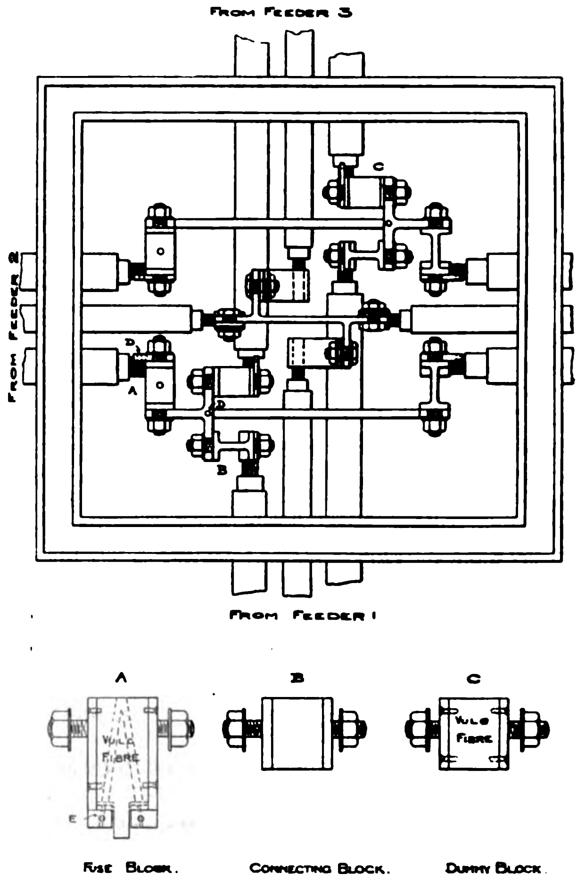


FIG. 7.

from Feeder 3 is isolated by the block C. The last-named block is inserted to hold the cables rigid to the bar, and thus prevent any sinking and displacement of the centres should the cables be left disconnected for a long period.

The fuse block A is shown with the body constructed of vulcanised fibre. This is a convenient material, but if heavy currents are passing normally, an entirely non-inflammable material would be preferably

employed. A copper fuse is inserted in the V-shaped fuse-way from the top, the ends of the wire being soldered into the ears at E. It is to be noted that the fuse-way is open at the top only in order that, if a fuse should blow, the metal and gases will be projected upwards, away from the fittings.

Tapped holes are provided at D D in which thumb-screws are inserted as a means of connecting ammeter, or switch, when testing, the block being removed. This is obviously useful in many ways.

As all the fittings are rigidly held together, although some of the lines may be electrically isolated, the bars may be supported entirely by the cables, thus greatly improving the insulation.

The joint box shown in Fig. 7 is of a type supplied by Callender's Cable and Construction Company, Limited, the cable lugs being slightly modified to take the interchangeable blocks.

APPENDIX II.

The interrupter and coil for fault localisation is indicated diagrammatically in Fig. 8. The interrupter consists of a double carbon and mercury break, the carbon-holders being operated directly by the

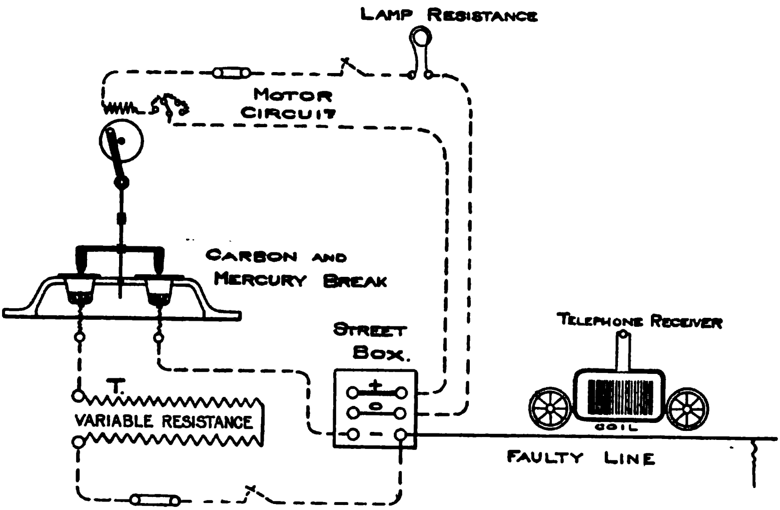


FIG. 8.

motor spindle by means of an eccentric pin and guide. The motor is run at about 150 revolutions per minute, and the current (usually about 10 amperes) through the break regulated by the adjustable resistance. The apparatus is packed in a box in such a way as to make it conveniently portable.

The coil is composed of a mile of No. 18 cotton-covered wire wound on a former, through which are placed charcoal iron plates

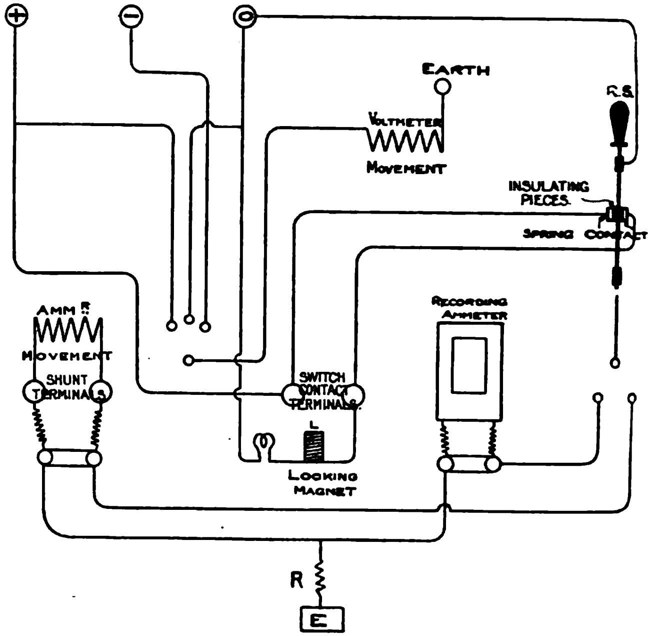


FIG. 9.—Diagram of Connections.

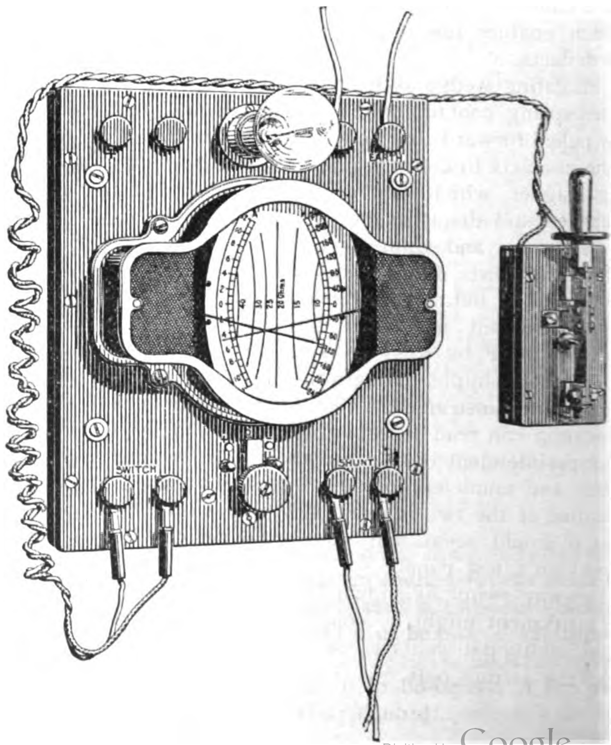


FIG. 10.—Ohmmeter.

to form a laminated core. The body of the apparatus is supported by two longitudinal beams fitting in grooves in the side of the core, and forming the carriage frame. The wheels have solid rubber tyres, and are set wide apart to admit of easy turning. The somewhat cumbersome construction is necessitated by the coil requiring to be as near the road surface as possible. The width of the wheel centres also enables the coil to be run over and along a trench. This is a great convenience if the fault-indication should be indefinite, and it is necessary to open ground in several places.

The coil is a modification of one made and used by Callender's Cable and Construction Company, Limited, for the purpose of fault location.

APPENDIX III.

An arrangement suggested for reading the combined insulation resistance directly is shown diagrammatically in Fig. 9. It consists of an ammeter and voltmeter contained in one case. The needles move in two parallel planes and overlap. Between the ampere and volt scales an ohm scale is marked. The scale is plotted for $\frac{V_2}{c} - R$, the point of intersection of the needles overlying the required reading of F. As V_2 and C cannot co-exist, a special attachment is made to the switch RS, which enables the ampere needle to be locked, while the volt needle deflects.

An insulating wedge is fixed to the blade of the switch which separates spring contacts when the switch is closed, but when it is slightly pulled forward. and before the "earth circuit" is broken, permits the contacts to come together, thus completing the circuit of a locking magnet, which retains the deflection C after the switch is fully opened and the voltmeter has swung to V_2.

The voltmeter and ammeter are entirely independent, and may be used for other tests if required. The voltmeter is provided with a three-way switch, but normally held on the neutral stud by a spring.

The instrument has been supplied by Messrs. Elliott Bros. The reading of F by Russell's Test with an ordinary voltmeter and ammeter is very simple, but with the automatic arrangement embodied in the combined instrument a "switchboard attendant" at any station or sub-station can read F instantly (say twice daily) and report to the mains superintendent if the insulation is below the standard. As a voltmeter and ammeter are required in any case, it only means the combination of the two in one case with the addition of an ohm scale, so that it would seem that such an instrument might be usefully employed on a test panel.

A two-way switch is shown in Fig. 9, but the ammeter portion of the instrument might be coupled across the switch R S (provided with an additional contact), so that the test would be made by opening this switch only.

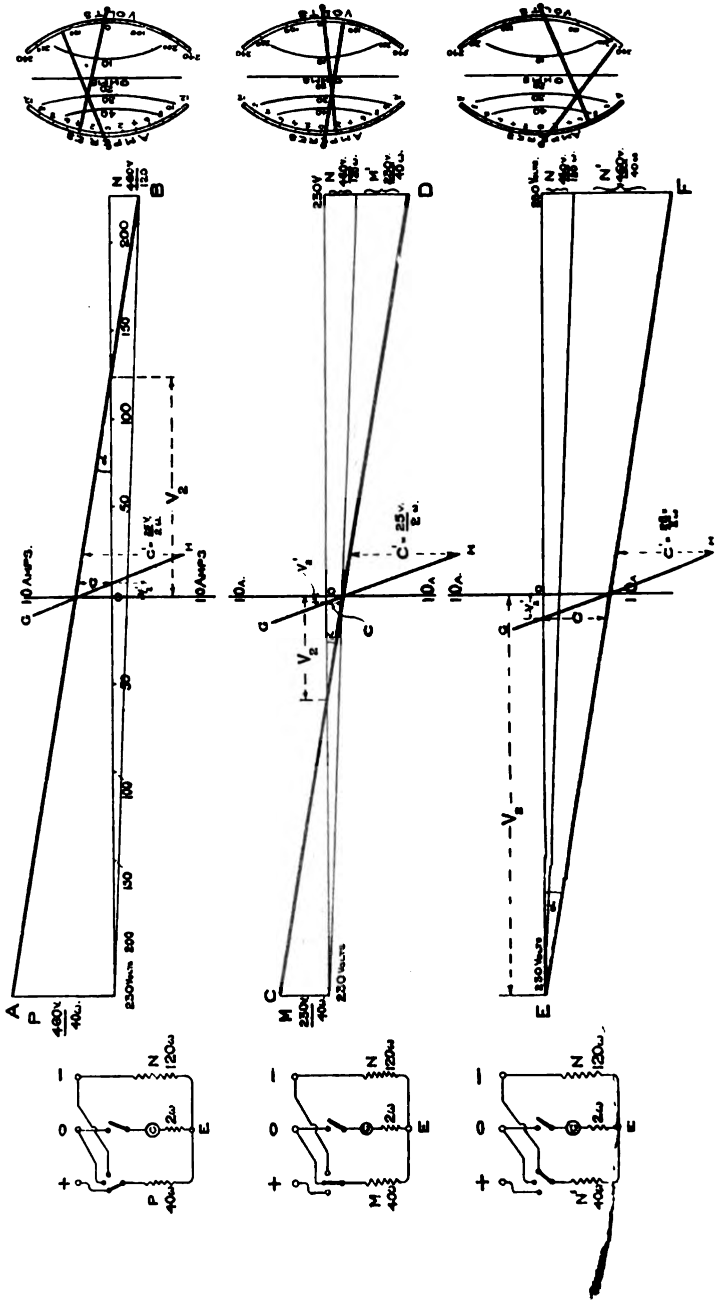


FIG. 11.

The range of the ohm scale of the particular instrument shown in Fig. 10 is small, and consequently is only suitable for use on systems where 40 ohms is well above the limits imposed by the Board of Trade regulations.

Fig. 11 indicates the operation of the ohmmeter under the various :onditions shown on the left of the diagram. Two faults of 120 ohms ind 40 ohms respectively are shown. The former is coupled in each :ase to the negative, and may be regarded as representing the normal nsulation resistance of the network; the latter is switched on either oole. The 2-ohm resistance in series with the ammeter circuit is R. The positions of the resultant lines A B, C D, E F in the diagram which is drawn in the manner suggested by Mr. A. M. Taylor, ournal 32, p. 873) represents the conditions obtaining when the o-ohm "fault" is switched on each pole in turn, the 2-ohm switch eing open. The joint insulation resistance, F, is of course the same 1 each case, *i.e.*, 30 ohms, and as this value $\frac{V_2}{c} - R$ is cot a, the ngle a must be constant, and the lines A B, C D, E F parallel, which seen to be the case. The line G H shows the effect of closing the ohm switch. On the right are shown the positions assumed by the mmeter needles, which intersect at the 30-ohm line, the volts and nperes corresponding to V_2 and C in each case. Obviously the strument may be used as a wattmeter by providing a scale reprenting the product of the ampere and volt readings.

Mr. A. M. TAYLOR: Dealing with one part of the subject Mr. Mr. Taylor. roves says, "It is also essential for the continuity of supply that the rth connection should be made through a resistance . . . for reasons o obvious to need repetition.' About a year ago the Editor of *The ectrician,* in a leading article, said it should not be so made. When wrote a reply the Editor appended a foot-note reiterating his statent. So that I am not so sure that it is perfectly obvious that a ard of Trade connection to the earth should be made through a sistance. The question is whether the Board of Trade connection ould be made dead to the earth through a fuse, or through a resistce of such a value as to limit the current it would carry to possibly) amperes if it had the whole potential, say 240 volts, of one side of a ee-wire system acting on it.

Dr. SUMPNER: The part of Mr. Groves's valuable contribution in Dr. Sumpner. ich I am most interested is the new instrument which he has devised. far as I know it is the first time an instrument has been devised emdying the principle of overlapping pointers, and I think the idea is able of extension. At all events, Mr. Groves has made an instrunt which will be very useful for the testing of electric light mains en combined with the test which Mr. Russell has pointed out. I h to make a remark about Mr. Russell's test, which is, I think, out two years old. Although I do not wish to under-value what . Russell has pointed out, I should like to say that it depends upon rinciple which is considerably over twenty years old. I have found principle very useful in many cases, and I think it is not so well

Dr. Sumpner.

known as it ought to be. It is this: supposing any two points of a system of mains, or of wires, are at different potentials from any cause whatever—I am speaking of direct currents—so that their potential difference is E, you can treat those points exactly as if they were the terminals of a battery whose E.M.F. is E; so that, supposing you connect them by means of a wire, and measure the current in that wire, you can by the ordinary fall of potential method determine the resistance between the two points. Mr. Russell has merely re-proved it in a particular case. I do not mean to say it is any detriment to Mr. Russell to have re-discovered that for a particular purpose; the merit lies in pointing out a really useful test which has not been pointed out before. But the principle is due to a French scientist, who pointed it out in the *Comptes Rendus* more than twenty years since.

Mr. Raphael.

Mr. F. CHARLES RAPHAEL (*communicated*): The Birmingham Local Section is fortunate in having submitted to it, this session as well as last, a paper on network testing. The subject is an important one, and is too frequently neglected by station engineers. If a man has not made up his mind previously as to the system which he will employ to locate a fault that may develop, he is not in a particularly good position to act promptly and with decision when the breakdown does occur. Moreover, if proper daily tests are made, the breakdown need never take place, as the fault may be discovered and localised before it has become bad enough to blow any fuses. With regard to the first part of Mr. Groves's interesting paper, I would only ask him whether he has actually fixed up a test panel such as he describes, and whether it answers in practice? There would appear to be some little danger of short circuits if the switches were inadvertently manipulated in the wrong order, and moreover, in a big network, one would imagine that the "kicks" of the middle wire ammeter, mentioned in section [illegible] would always occur on earthing one of the outers. However, the fact that Mr. Groves recommends daily tests by one of the earthed ammeter methods is the main thing, and in this recommendation I cordially support him. With the latter part of the Paper, on the other hand, I am bound to disagree, for Mr. Groves insists emphatically, in his last paragraph but one, that we hold contrary opinions. To meet his criticism that my tests are too elaborate and necessitate the employment of instruments of too sensitive a nature, I think I need only call attention to the annexed drawing (Fig. 12) of one of Messrs. Nalder Bros. & Co.'s direct-reading fault-localisers, in which my ideas are carried out. This "sensitive" instrument consists of a wire stretched over a scale, a key, and two contact-makers or "jockeys"—nothing more. The second contact-maker could be dispensed with; it is added to make the instrument direct-reading, and to save the engineer the "elaborate" calculation of multiplying by a three-figure number and dividing by a thousand after the test is completed—in fact, it saves time. As auxiliary apparatus, a battery of two or three storage cells and a portable galvanometer such as is carried in an ordinary testing set, are all that are required. I contend that a wire stretched on a scale, a tapper key, a few secondary cells, and a portable galvanometer constitute a less elaborate testing set than a motor driving a carbon

Mr. Raphael.

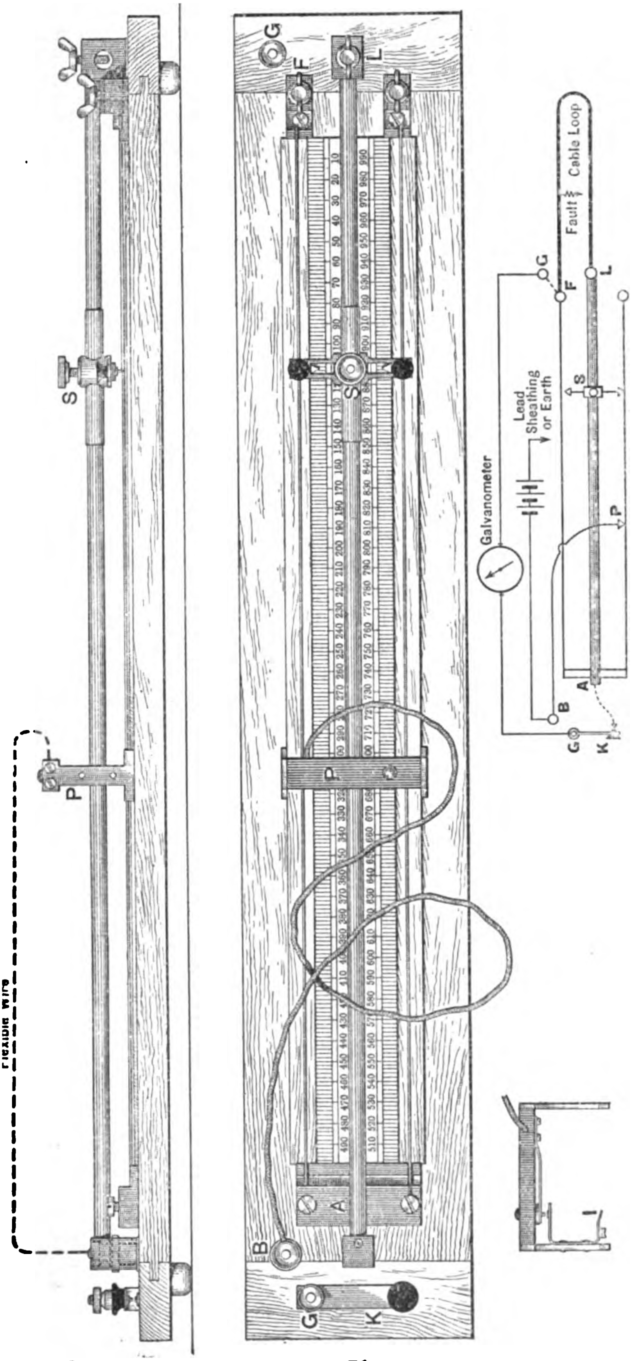


FIG. 12.

Mr. Raphael.

and mercury break, a lamp resistance and starting switch for the motor, another variable resistance, a telephone receiver, and a coil of wire on a perambulator. Then, as to "practical difficulties," I have carried out scores of localisation tests by the loop methods, and I have never known one to fail. Mr. Groves cannot say as much for his induction method. Of course I have taken reasonable care to see that the connections were properly made, and devoid of appreciable resistance, that the instruments were clean, and that the test was carried out intelligently. This should not be a difficulty, for a test so rare in ordinary practice as a localisation test should be carried out by a skilled engineer and not by a workman. I may add also that my results have been successful whether employing as the "bridge" an expensive resistance box, a simple long piece of binding wire soldered across the ends of the cable loop, or the instrument made by Messrs. Nalder Bros. to which I have alluded. There is no reason why the results should not be absolutely accurate—within a small fraction of 1 per cent. of the length of the cable loop—and I understand that a member of Messrs. Nalder Bros.' staff has localised faults within a yard on a length of several hundred yards of thick main forming part of the Westminster Electric Supply Corporation's network. Another advantage in favour of the loop method is that the fault need not be a dead earth; faults of several hundreds of ohms resistance can be localised accurately simply by adding to the battery power used, or by employing a more sensitive galvanometer. In using the instrument the cable loop is connected up to the stretched wire as in the diagram, the slider S is set to mark off the length of the loop, and the slider P is moved up and down the wire until the galvanometer or detector indicates balance. The reading opposite the slider P is then evidently the distance of the fault from the terminal F. I now come to the induction method; and here again, although modesty should prevent my mentioning my own work on the subject, the love of accuracy compels me to remark that Mr. Groves will find full descriptions of these in the book to which he has alluded, and a review of the circumstances in which the methods are and are not reliable. The chief difficulty in carrying out this induction test with satisfactory results is that, in the case of lead-covered or armoured cables, the hum or beat in the telephone does not cease at the fault, but gradually diminishes. The reason for this was pointed out clearly by the late Mr. R. C. Quin in a paper read before the Municipal Electrical Association in 1897, which will be found in the M. E. A. *Proceedings*, or in *The Electrician*, vol. xxxix. p. 437. The current escaping at the fault does not flow straight back to the station along the sheathing; if it did, there would be no sound in the telephone at all, for the inductive actions of the two currents would neutralise one another. Some flows straight back, but some continues along the sheathing after the fault is passed, and leaks back to earth through the ground or along any other pipes or mains. Suppose, for instance, that a current of ten amperes is applied to the cable, and that eight amperes flow straight back from the fault by way of the sheathing. The extra two amperes through the copper conductor will induce the desired current in the telephone coil, but imme-

tely after passing the fault there will still be two amperes flowing ough the sheathing in the direction away from the station. Thus effect on the telephone and search coil will be the same as on the er side of the fault, and will only diminish gradually as the current ks away to earth. When another main crosses the line, the current y flow along that, whether the main be an electric one or a gas or ter pipe; and Mr. Quin described how, on one occasion, he found of his assistants in search of a fault with a search-coil and phone, tracking a gas-pipe down a side street in which no cables l been laid at all. Mr. Raphael.

Mr. GEO. BARNARD (*communicated*): I should like to add my experi-e as to the final location of faults by the induction method (G). I 'e had experience of this way of finding faults for the last fifteen rs, and for single cables of short lengths I have been successful, but cables a mile or two long I do not consider this method quite satis-tory owing to the condenser effect due to capacity, etc., it being sible to get a vibration in the telephone with a cable testing many gohms to earth. I much prefer the drop of potential way of loca-g them. When I first started to localise faults by the telephone thod, I used a separate induction coil and disconnected the faulty le from the source of supply and had it quite free. Later I carried some tests similar to Mr. Groves's method without disconnecting the le; I broke by hand the current to earth through a water resistance he first place, and later through several high candle-power lamps is to get about ten amperes through the fault. It is easy enough to lise faults in this way when you have to deal with cables not having metallic sheathing, or with iron troughs with tile cover; but if are lead sheathed or armoured, or if the iron troughing has a al cover, or the cable is drawn in an iron pipe, this method then its drawbacks, it being very difficult to locate faults with any ount of certainty. I have tried another method with a certain ount of success by having the current broken through a contact-aker at both ends of the faulty cable; one has to be a slow break the other a quick one, so as to give a different note in the phone, and where you get the two notes at their loudest pitch there ie position of the fault, as you do away with the tapering effect of vibration in the telephone. This is the best way that I know of n metallic-sheathing conductors are used; but, for long lines and system of mains, I prefer the loop test by the "drop of potential" hod, from which I have obtained better results. Mr. Barnard.

Mr. A. P. TROTTER (*communicated*): Possibly because the genera-plant might be considered outside the scope of this paper, no sion has been made to the advantage of using a separate machine supplying a faulty network which has been disconnected from the by the linking fuses. The use of such a machine presents two antages. It takes the leak off the busbars, and it allows a higher stance to be put between the middle or neutral and earth. This stance can be adjusted to suit the size of the network, and need be smaller than will hold down the sound main of the disconnected ict to 250 volts from earth. Fig. 1 is scarcely less complicated Mr. Trotter.

Mr. Trotter. than the intricate diagrams in Mr. A. M. Taylor's recent paper. Those like myself who cannot give much time to studying such problems, but who would like to get a general idea of the tests, would be greatly helped by a set of different diagrams for different tests; heavy lines showing the circuits and switches in use in such a test, and the others being shown lighter or dotted. I do not like to criticise the joint box shown in Appendix I., as I have no practical experience with it; but from such experience as I have gained by the investigation of explosions in street boxes, the clearances seem to be rather small. I should like to see three separate boxes used instead of one—one containing A, B, and D, another the neutral connections, and another containing C and the mains connected therewith. Short circuits in street boxes are too common, and explosions in such boxes occur with a frequency which is not creditable to English engineering. A small explosion unlikely to have caused any injury to the public often breaks or lifts the lid and lets it drop into the box, causing a serious short-circuit. The use of separate boxes avoids this. I hesitate to criticise the fuse block without seeing it, but I do not hesitate to object to the use of vulcanised fibre for any such purpose as this. I understand that a simple tin fuse shunted by a much smaller Mordey fuse breaks large currents very quietly in street boxes. It is not uncommon for the blowing of fuses to be reported by the police to the Board of Trade as "explosions."

Mr. Groves. Mr. GROVES (*in reply*): With regard to the use of a controlling resistance in the neutral earth circuit, it seems to me best to employ a low resistance which is sufficient to prevent serious damage to the mains, or interruption of supply, by the operations of any navvy who chooses to puncture them, or by any other accident. If you put a fuse in it is worse than nothing, because you might think you had an earth connection when you had not. Perhaps in the middle of the night a momentary fault might turn up and blow your fuse. It is a much more satisfactory thing to feel that your leakage is controlled. Of course, if you use a resistance you must at the same time be conscientious about it; you must not be content to think that that resistance prevents a fault doing any serious harm, and that therefore it does not matter. You must have sufficient interest in the mains to keep the insulation sound; but it seems to me that it is asking rather too much of a Mains engineer to require the neutral to be put dead to earth without a fuse or resistance, and of the two the resistance is preferable. The effect of a low resistance is to lower slightly the potential of the sound main with regard to earth from what it would be should the fuse blow, which is a point distinctly in favour of the resistance as opposed to a fuse. When the leakage to earth is small the resistance has obviously little effect in displacing the potential of the neutral. What Dr. Sumpner has said is most interesting and, I think, non-contentious.

(*Communicated*): I regret that Mr. Raphael's communication did not come to hand in time to be read at the discussion which followed the reading of my paper. The panel illustrated is a simplified form of one which I have used for some considerable time. I am unable to see how a short-circuit can occur, unless an attempt is made to

'e the three-way switch T S with the switch E S closed and the stance cut out, in which case an arc might bridge the contacts of . With slight modification it could be made even "fool proof." he neutral is sound, the tests described being devised to keep it there should be no appreciable "kick" on the middle wire neter when either of the outers is earthed. If there is a "kick" cause of it should be hunted down. Mr. Raphael has misinter- ed my remarks as to some of the localisation tests described in book. I did not say they were too elaborate, but that it would difficult to elaborate on them, *i.e.*, *improve* on them as tests ı sensitive instruments. Considerable experience has led me to 'er the induction method, which has proved almost infallible on ns without armouring or lead covering. The gear is in a very able form, and can be run out like a fire engine in an emergency, no time is lost in cleaning connections, adjusting instruments, and, ve all, in removing the slight and varying leakages due to surface ıpness, in street boxes which are so liable to upset the deflections of ılvanometer. My remarks might be taken to imply that the induc- methods are not referred to in Mr. Raphael's book; this also I did intend, and after writing the paper I was careful to look through second edition to see if there was any occasion to modify my views, I found no cause to alter them. Mr. Raphael's book is a most ul one, and should be in the hands of all Mains engineers. I dealt rely with "rough and ready" tests as distinguished from tests such hose described in the latter part of Mr. Raphael's communication. vould be of no interest to say that faults had been localised by ıns of loop or other similar tests, but I hoped an account of ɜriences with the induction method, which is perhaps less generally ıloyed, might produce discussion. Mr. Barnard's remarks are of ıe as representing the results of long experience. I have not ɔuntered the condenser effect to which he refers, to recognise it as ı, and the point is interesting. As to the double break method, ink if serious trouble arises in using the simple induction method, a › test is to be preferred. Mr. Barnard's remarks corroborate what generally admitted fact, and which perhaps I did not sufficiently ›hasise, viz., that the induction test cannot be universally employed, that it has many shortcomings when attempted on systems of ns other than that on which I have had occasion to use it with ɜllent results, *i.e.*, on a solid system without metallic sheathing. ere armoured or lead-covered cables are laid, localisation tests ıt be adapted to the system of earthing resorted to. Mr. Trotter ıtions the advantage of using a separate generator to feed a faulty vork. It would certainly be an advantage if the temporary strain on the sound cable by a fault of the opposite pole could be limited small area. The interchangeable blocks in the network boxes were gned to make the system of mains more "flexible" without increas- the number of the street-boxes. Mr. Trotter suggests, I think, that ɜparate box should be used for each pole. The letters A B C r to the different types of blocks. A sectional view of Fig. 7 ıld perhaps have shown the clearances to greater advantage. Mr. Groves.

Mr. Groves. Mains engineers will regret that Mr. Trotter's wide experience has caused him to form a generally unfavourable opinion of their ability to design satisfactory street-boxes, but I am very glad to know his remarks cannot apply to the boxes shown in Fig. 7. I have had eight years' experience with some hundreds of these boxes, and I cannot recall a short-circuit in them except an occasional one, common to boxes of all types, caused by carelessness of workmen when manipulating the connections, to which, I take it, Mr. Trotter does not refer, as they would hardly be classed as "explosions," even by the police. I should have liked to know the nature of Mr. Trotter's objection to the use of fibre (with the qualifications made in the paper) in the construction of the fuse block. The question of insulation does not occur, and it is not proposed to use this material where the fuses would be at a higher temperature under ordinary loads. It is mechanically superior to porcelain as a support for the bars, and it is unaffected by the sudden blowing of a fuse. I have been unable to find any better material than porcelain for heavier fusing blocks; in fact, this would meet all requirements if it would stand strain or knocking about. The fibre fuse block has been short-circuited across 440 volts without suffering any harm. I have, in conclusion, to thank those gentlemen who have kindly contributed to the discussion.

DUBLIN LOCAL SECTION.

NOTES ON SOLID RAIL JOINTS.

By PERCY S. SHEARDOWN, Associate Member.

(*Paper read April* 14, 1904.)

When electric traction first came to the front, it soon became obvious to the pioneers that more was needed than simply to equip cars with electric motors and controllers in place of the horses or mules which had previously been used. Among other things that very soon gave trouble was the car track as laid for horse haulage, which, considering the changed condition of things, was not to be wondered at. A horse car of the old type complete weighed about 3 tons, and was pulled quietly over the track at an average speed of somewhere about 6 miles an hour. With the new order of things the weight of electric cars quickly increased to 8 or 12 tons, and they carried a load of passengers of 3 to 5 tons. The cars were propelled through the wheels at a speed which, in the United States, soon approached 20 or 30 miles an hour, and under these changed conditions it does not seem very strange that the old track work should have proved inadequate. It was not indeed so much the track as a whole that had to be redesigned, as the support at the ends of the rails or the rail joints. The latest form of track for horse-car work comprised a girder rail of a weight as high as 60 or 70 lbs. per yard laid on a 6 in. bed of concrete. This is more or less standard practice for electric tramway roads to-day, except that the weight of rails has been somewhat increased, and also the length of each section of rail; but trouble with the joints immediately developed, the pounding action of the heavy cars travelling at a high speed causing the ends of the rails to become depressed, and when this once started, matters went rapidly from bad to worse. The trouble was to a large extent alleviated by the use of heavier and more rigid fish-plates, which were more carefully fitted to the web and underside of the rail. In many cases sole plates are also used, which are bolted or clamped on to the bottom flange of the girder rail, the fish-plates still being held in position by large fish-bolts and nuts; but, as is well known, with all bolts subjected to vibration there is always a tendency for the nut to slack back, and it occurred to many manufacturers interested in this class of work, and also to many street railway engineers, that a solid form of joint or continuous rail would be most acceptable.

It may seem strange that such trouble should be met with in electric tramways, when steam railroads carrying much heavier rolling stock and travelling at much higher speeds, while using lighter rails and fish-plates, should be practically free from this trouble; but a small amount of consideration will show that the conditions are absolutely different.

The difficulty is not in making a rigid joint with the ordinary fish-plates and bolts, but in keeping the fish-plates tight up to the rails; and on railways where the rails are not buried, this process of tightening up the bolts is continually going on. Moreover, in ordinary railway practice where the rails are fastened down to wooden sleepers laid on ballast, there is an amount of spring and yield throughout a long section of track which is quite absent in a 6 in. or 7 in. girder rail laid on a solid bed of concrete.

Many forms of solid or continuous rail joints have been thought out and patented, but the only three which have proved of much use in practice are known as the Falk Cast-welded Joint; the Electric Welded Rail Joint, with which is associated the name of the Johnson Company and later the Lorain Steel Company; and more recently a system of producing a cast-welded joint by a method known as the Thermit system. The Falk cast-welded joint was first put to practical use in St. Louis in 1894, and during the following six years this process was very largely employed, over 600,000 joints being made by the Falk Manufacturing Company alone. Many of the large street railway companies in the United States also worked the process themselves under licence. The method of procedure was as follows:—

FALK CAST-WELDED RAIL JOINTS.

The "Falk" system consists in casting an iron sleeve round the sides and bottom of the rail joints, the rail ends being first placed firmly together. In cases where they do not absolutely touch, thin plates of steel are driven in between the heads of the rails before casting. Before fixing the iron moulds, the sides and bottom of the rail are cleaned. In order to give good results, the cast iron used is of special chemical composition, and is run at a much greater heat than is used in making ordinary castings. The metal as it runs into the iron moulds cools rapidly on the outer surface, thus causing a tremendous pressure to be exerted on the metal, which is still in the molten state, in contact with the web and foot of the rail. As the metal is poured in from one side and comes in contact with the web of the rail at the greatest heat, this, the thinnest part of the rail, is brought to a white heat, and, owing to the pressure exerted on the melted cast iron, the latter is practically forced into the interstices of the steel, thus not only making a thoroughly good mechanical joint, but also ensuring a good electrical joint. Although not actually welded, the result obtained is practically equivalent to a weld, as, if the cast iron is torn away from the web of the rail, it usually brings away part of the rail with it. The Falk Company state that, on examining a welded joint which has been sawn through, the section of the web can no longer be clearly distinguished, and it is impossible to say where the cast iron ceases and the web of the rail commences.

The cast iron must necessarily be melted close to where the work is being done, and for this purpose a regular outfit is required. The apparatus consists of a small cupola with the necessary steam engine or turbine fitted to a truck to be drawn by horses; also the sand-blast

machine. The Falk Company claim that the sand-blast method of cleaning the rail ends was perfected by them in 1897, and they state that this has proved the best means of getting the rail in condition for a perfect joint. This machine is operated by an electric motor driving an air compressor which at a pressure of about 20 lbs. throws a stream of sharp sand at a high velocity against the sides and bottom of the rail, removing all scale and rust, and leaving the surface clean and bright and in perfect condition for amalgamation. In repairing the worn-out joints of old rails subsequent to the process of pouring the metal, various forms of clamps are used which regulate the amount of rise in the rail, reducing the surface to be dressed down to a minimum. After the joint is made a special machine, consisting of a flexible shaft-grinder and an electric grinding car, is put in operation, with the result that the finished jointing of an old track presents, it is said, as smooth and even a surface as can be produced. In addition to its strong mechanical construction, it is claimed that the electrical conductivity of the joint when cast-welded in this manner is greater than the conductivity of the rail itself; and from what the author can learn, this is substantiated by evidence of independent engineers who have had this system of rail joint under their personal notice.

The section of the cast-iron joint is so designed as to have at least the same tensile strength as that possessed by the rail. The cast-welded joints are generally about 14 in. long, and the weight of cast iron varies with the weight of the rail from 70 to 140 lbs. per joint.

The Lorain Steel Company's Method.

This system is now being used on the Dalkey section of the D. U. T. Company at the present time. The process of electrically welding tramway rails in the street as applied by the Lorain Steel Company comprises three distinct operations. The machinery is mounted on self-contained cars of suitable design, each equipped with its own motor for locomotion. The running gear of these cars is provided with threaded axles, so that the machine can be used to weld tracks of different gauges. New rails may be welded either before or after the paving is in place, space being left at the joints to permit the entrance of the welder. In the case of old rails the paving is lifted around the joint, and, the fish-plates and bond wires being removed, the rail ends are then raised to the proper level.

In the welding process the first operation is that of the sand-blast, by means of which all dirt, rust, and foreign matter is removed from the rails at the places where the welds are to be made, and from the corresponding points on the bars used in making the joint. The apparatus for this work consists of a 10-H.P. motor driving an air compressor, a tank for the storage of air, and a bin for holding a supply of sand. A sand mixer of the Tilghman type is also provided. By means of a hose and nozzle, the operator directs the blast of air carrying the sand against the rail until all foreign matter has been removed. The bars are similarly treated, and the joint is ready for the actual operation of welding.

The apparatus for welding is carried on two cars coupled together by a special form of slip coupling which permits a sufficient range of movement for the car carrying the welder proper to be moved from one weld to another of the three welds necessary in making a joint, without the necessity of moving the second car. The welder itself is hung from a bale on a crane extending out beyond the end of the car. This crane permits of lowering and raising so that the jaws of the welder can engage the sides of the rail, and also can shift the welder from one side to the other to engage each rail of the track. The crane is operated by friction clutches from a shaft in the car which is kept running continuously by a 5-H.P. motor. This motor also drives a small rotary pump for regulating water through the welder transformer and the faces of the contacts to keep them cool. After the water has passed through the welder, it goes to a cooling tank on the top of the car. The welder itself is an alternating-current transformer, the primary winding of which consists of two coils in parallel of forty-four turns each. The secondary coil is a single loop of copper, of large cross section, the terminals of which form the contacts or jaws, which engage each side of the rail, and between which the weld is made. The secondary winding is so made as to enclose entirely the primary coils, which are insulated in oil. On each side of the transformer and supporting it, but insulated from it, are the two large levers, hinged together about two-thirds of the distance from the top, for transmitting the necessary pressure to the weld. These levers are connected at the top by a hydraulic jack. A hand-pump for forcing water into the jack is bolted to one lever. A pressure of 4,000 lbs. per square inch is obtained on the $3\frac{7}{8}$ in. diameter rams of the jack, the leverage on the arms increasing this, so that about 37 tons total pressure is developed on the weld.

In making a joint, flat-rolled steel bars are used, having at each end a boss or projection on one side, which forms the contact point between the bars and the web of the rail, and confines the welded area to these sections. A flat strip of steel, $\frac{1}{8}$ in. thick and 1 in. wide, is placed across the middle of the bars on the same side of the bosses. The bars are supported on small blocks and placed across the joint, so that the strip engages the web of both rails. The middle weld is a vertical one, and made the full width of the bar; the end welds are horizontal.

The welding train of two cars is moved up to a joint, between the end of which a shim or small section of rail has been driven, in order to make a tight butt joint, the welder is swung into place and the jaws made to press against the bars on each side of the rail. The current is then turned on, and flows from contact to contact through the bars and the rail web. By altering the pressure on the jaws, the resistance of the several junctures is increased, and the whole is soon brought to a welding heat. As soon as this stage is reached the current is cut off, and simultaneously the pressure is brought up to the full amount. Pressure is then lessened, and the welder car moved back to bring the jaws opposite the first extremity of the bars. The same process is again followed here, except that when the final pressure

has been applied it is held there, and the weld permitted to cool under pressure until the metal is cooled sufficiently not to show any glow. The welder is then moved forward to the other end of the bar and the process repeated, after which the welder is raised and moved to the other side of the car to engage the opposite joint.

A remarkably tough weld is secured by holding the pressure after the weld is made. It will be noticed that only the end welds are thus treated; as the centre weld is not subjected to the same stress, it is not essential to have toughness there.

It has been found desirable to weld the ends of the bars while the bars are in an expanded state. By making the centre weld first, and proceeding at once to the end welds without waiting to cool the centre weld under pressure, the greatest elongation of the bar is secured. After the ends are welded and the bars cooled off, they contract and exert a powerful pull to bring the abutting rail ends together, thus closing the slightest opening and leaving practically no joint at all. It is at once apparent that this is an important consideration in the manufacture of a continuous rail, for if the abutting rail ends are not brought firmly together the metal in the head of the rail will have a chance to spread in service into the opening between the rails, and thus in time will cause a low spot in the rail head. Inasmuch as the bars are always in a state of tension, it follows that the rail itself enclosed between the bars is in a state of compression. Any contraction of the rail itself between the joints will be transmitted to the rail welds, and it is therefore necessary to have these welds exceedingly tough to withstand the strain. The object of the centre weld is simply for vertical stiffness, and to prevent any movement of the rail ends. The actual current used in welding is from 25,000 to 30,000 amperes at a pressure of about 7 volts.

In the car attached to the welder is carried a rotary converter for changing the direct current from the overhead wire to an alternating current. The current in the primary coils of the welder is 300 volts alternating, 40 cycles; the direct-current side of the rotary will take current from 325 to 600 volts from the wire, and by means of suitable regulating apparatus the output on the alternating side of the welder is kept practically constant at 300 volts, with regard to the fluctuations on the line. On a line voltage of 500 about 225 amperes are required, or it takes about 125 k.w. to make a weld, the current being on about 2½ minutes to each weld.

The finishing operation in the process consists of grinding the head of the rail to true surface. In welding new rail there is little occasion for the use of these machines. In old track where the rail ends have been battered, the receiving rail is purposely welded higher than the other. The grinder is then used to grind out the inequalities in the head of the rail and bring it to a true surface. The grinder consists of an emery wheel mounted on a carriage, having two rollers which are about 4 feet apart. The carriage is let down on the rail, so that the rollers roll along the head of the rail, the emery wheel being over the uneven portion of the joint. The carriage is connected with a motor on the car by a swing frame, thus enabling the operator to move the emery

wheel back and forward over the joint, while the car remains stationary. By means of a hand wheel, the emery wheel is gradually fed down, and it is moved forward and backward after the principle of a carpenter's plane, until the whole surface is brought to a true level. With the final operation of grinding, the joint is left complete.

The work embraced in contracts undertaken by the Lorain Steel Company in connection with electric welding includes the work of sand-blasting the rails and bars, the supply of welding bars, the actual welding operations, and the grinding of the rails afterwards to surface. The tramway authorities are required to remove the paving, take off the fish-plates and the old bond wires, and replace the paving after the operation is completed. It is of interest to note in this connection that it is not necessary to disturb the concrete bed of the rails in any way, and the facility and expedition with which the work is carried out certainly presents many advantages which tramway managers have not been slow to appreciate.

As a continuous process, working day and night, it takes about 13 minutes to complete a joint, and 80 joints in 24 hours is considered a fair average. The bars used are 1 in. by 3½ in., the length varying with the form of joint previously used. On new rails where the ends are left blank especially for welding, the length is 18 in.; on old rails the bars must be long enough to reach over the old bolt and bond holes, in some cases requiring bars as long as 48 in.

Another advantage claimed for the electrically welded joints is the high conductivity obtained by the use of this process. The electric welding bars are made of low carbon steel, and are therefore of low resistance, and the cross section being large, the conductivity of the joints should average over 50 per cent. higher than the rail itself.

The Thermit System of Welding.

Thermit welding is a chemical process by which the tremendous heat generated by the combination of finely powdered aluminium with oxide of iron (Thermit) is employed to produce a welding temperature at the rail joints.

The temperature attained by the combination of aluminium with oxygen is stated by Professor Boys and others to be somewhere in the neighbourhood of 3,000° C., while the melting-point of iron is given at 1,070° C., and steel 1,530° C., so that provided that enough of the mixture is employed, it is easy to produce a welded temperature in the ends of the steel rails.

The Thermit is usually melted in a crucible, the process being started by placing a little ignition powder, composed of finely divided peroxide of barium and aluminium, on the top of the Thermit. This can be lighted by a fusee, and generates enough heat to fire the charge; or magnesium ribbon may be employed. The reaction takes place very rapidly, the reduction of 20 lb. of Thermit taking under one minute. There is, then, at the bottom of the crucible about 67 per cent. by weight of pure iron, the balance of the mixture being light aluminium slag, which floats on the top.

The Thermit welding may now be carried out in one of two ways. If the weld is to be a clean butt weld as in jointing two lengths of pipe, the melted mixture is poured from the top of the crucible, so that the slag comes first in contact with the cold surface of the article to be welded, which chills the slag a little and forms a sort of film over the surface and prevents the molten iron which follows from adhering to the surface. By this method the heat of the Thermit only is employed to raise the parts to be welded to a welding temperature.

The second method of using Thermit, which is the one employed in rail welding, is to run the melted alloy from the bottom of the crucible. In this case the iron comes in contact with the rails first. It will, if this process is carried out with the proper precautions, melt the surface of and adhere to the rails, becoming, in fact, a single piece with them, and if the slag follows the iron it will fill up the upper parts of the mould, and the whole rail from top to bottom will be brought to a high and uniform heat. Now, the temperature is so great that Thermit iron run in in this way, at once melts through the rails where it meets them. The temperature is, in fact, unnecessarily high. To reduce it, and at the same time increase the quantity of iron which a given charge of thermit will yield, Dr. Goldschmidt has adopted the practice of mixing with the thermit about 15 per cent. by weight of wrought iron in small pieces, such as punchings. Now, thermit will be found to contain very nearly half its weight of iron, the whole of which is available as iron, so that when 15 per cent. of iron is added, the yield of thermit becomes nearly two-thirds iron. Tram rails which weigh 100 lbs. to the yard require for a complete and satisfactory weld about 22 lbs. of thermit, and so nearly 14 lbs. of iron are available to form a strengthening shoe at the joint; a shoe not bolted or clamped, but absolutely one with the rails, and consisting not of cast iron, but of what is in reality a very mild steel or melted pure iron, free from carbon, and therefore soft and malleable.

Compared with the costly and elaborate plant required by either the electric system of welding rails or the Falk system of casting, the apparatus required for the thermit system is conspicuous by its exceeding smallness. The outfit consists of a crucible, which is not made of the material used for ordinary crucibles which are heated from an external source, but consists simply of an inverted cone of perforated sheet-iron casing lined with an inch or more of magnesia. This crucible is placed over the rail on an ordinary tripod in such a position that when the crucible is tapped, the metal will run properly into the mould formed round the ends of the rails. The moulds are simply sand moulds of the right form such as are used in foundries. Before the moulds are put round the rail joints the ends of the rails are carefully cleaned, and if they do not butt tightly, a section of rail is driven in between them. The rails on each side of the mould are tightly gripped between clamps connected by powerful screws, and after the metal has been poured and the rail ends have been brought up to welding temperature the screws and clamps are tightened up. In this way a butt weld is formed between the ends of the rails which helps greatly in securing the desired rigidity.

In concluding the description of the three processes, I should like to offer a few remarks:—

The Falk system of cast welding has undoubtedly been a success in the States, and was much employed between 1896 and 1900, but since then this process has been apparently more or less ousted by the electric welding process. One of the drawbacks to the continued commercial success of the cast-welded joint appears to have been the size of the equipment required and the fact that it proved expensive unless a large number of joints could be poured at one time, which is often inconvenient. With regard to breakages, these appeared to be small—from the evidence from various sources examined, not more than from ½ to 3 per cent.

The electrical conductivity appears to be good—better, indeed, than with the usual allowance of copper bond. The process has been employed to a certain extent on the Continent, and at Norwich and Coventry in England.

With regard to the electric welding process, this is a good example of the determination with which Americans will expend energy, time, and money on any new process which they believe can be made a commercial success. The Johnson Company, who were the predecessors of the Lorain Company, are said to have expended in the neighbourhood of £200,000 on various experiments in connection with electric track welding, though up to the beginning of 1897 the process could not be called a practical success. In the earlier experiments the splicing bar was simply a short slab of steel extending out a few inches on each side of the joint, which was welded up solid. The resulting troubles were, first, the head of the rail got so hot that it was softened owing to the heat producing a physical alteration in the composition of the steel; and secondly, the rail used to frequently fracture, the fracture practically always occurring through one of the old fish-bolt holes.

Until the nature of the apparent change in the structure of the steel could be understood, the Company withdrew from the field and entered upon an exhaustive series of experiments. Various methods of heat treatment after the weld was made were tried and discarded. Finally, Mr. H. F. A. Kleinschmidt, in endeavouring to prevent the spread of heat after the weld is made, discovered a very simple process which entirely overcomes any change in structure of the steel, and produces a weld of the greatest toughness and strength. This process consists in making a weld from a boss on a bar, instead of from a flat bar. As the boss is the only portion of the bar which comes in contact with the rail, all the heat is concentrated at that point. As soon as a welding heat is reached the current is cut off, and simultaneously a heavy pressure is exerted directly over the weld, and artificial means are provided for hastening its cooling while under pressure. The comparatively cold portions of the bar surrounding the boss prevent the more plastic metal from spreading, and the heavy pressure so confines it that in cooling there is no chance of coarse crystallisation. In other words, the effect is exactly the same as hammering or working the steel.

The results obtained experimentally by the Lorain Steel Company

have been amply borne out by practice. Even with a strain of 350,000 lbs. they have never succeeded in shearing off a weld made in this way.

The trouble with regard to the breaking of the rails through the old fish-bolt holes was largely reduced by reaming out the holes, and it is interesting to note that much more trouble was experienced with fractures in rails in which the holes had been punched than in those in which the holes had been drilled.

With reference to the thermit system of welding, this is a most interesting process and one which would appear to have a great future before it, not only for the electric welding of street rails, which is only one of the many applications for which it is admirably suited Several rail joints made by this process are under test on our last extension on the Drumcondra line since September, 1903, and so far appear to have satisfied expectations, but unfortunately the car mileage on this section is small. With regard to the process as carried out there, it appeared that, while making an excellent joint, the arrangements for directing the molten metal from the crucible to the pouring hole in the mould wanted more development in order to make it perfect, as it was not uncommon for the metal to strike the head or the cheek of the rail on its way to the mould, melting the rail where it came in contact with it.*

With regard to the electric conductivity, I may say that both the electrically welded and also the thermit welded rail joints that I have tested have given satisfactory results, the conductivity of a length of rail with a joint in it being as good, or even in some cases better than a similar length of unjointed rail.

The reason why the Dalkey line track has been electrically welded is that, when put down in 1894, although the rails were of good quality and road-bed good, the method of fishing the joints was decidedly too light for the weight of the cars and the speed at which they run. The joints became depressed, and though the permanent way department tried several remedies, such as heavier fish-plates, sole-plates, etc., the joints were still deteriorating, and it appeared as if they would become hopeless long before the body of the rail itself was worn out. Consequently the present undertaking was carried out, in which the depressed rail joints were raised up level as far as possible, and in some cases the receiving rail raised a little higher and then welded in position and levelled off with the emery grinder. Although the blow at the joint has not entirely disappeared, it is much less noticeable than formerly; and moreover, as the joint is solid and the rail practically continuous, with no fish-plate nuts to slack back, there is every hope that the joints at all events will deteriorate no further.

With regard to the fears often expressed that long lengths of rail laid with solid joints will give trouble when extremes of temperature are experienced, I believe that such fears are practically groundless. It is well known that on steam railways where the rails are subject to

* Since writing the above, I learn from the English representative of the process that the arrangements for pouring the metal have been very much improved and this trouble quite overcome.

wide variations of temperature care has to be taken to arrange for the expansion of the rails, but the conditions under which a railway line and a tramway line are subjected to heat are perfectly different. In the railway line the whole of the rail is exposed to the heat of the sun, and, except for the side grip of the wedges in the chairs, there is nothing in the way of side pressure to prevent the rails from expanding or contracting throughout their whole length. In the case of the tramway rail, however, the tread only of the rail is exposed to the heat from the sun, and the area of this is only about 10 per cent. of the total buried area.

The grip of the sets depends to a certain extent on the material they are grouted in with, and for this particular purpose cement is no doubt far superior to pitch, which, being a liquid or semi-liquid, will yield to a continuous pressure, and in practice probably, even on a hot day before the rails could have moved to any extent, the evening would have come on and the rails would be cooling down again.

With regard to buckling, the pressure of the sets on each side of the roadway and the weight of the sets on the bottom flange proves quite enough to prevent the rails shifting in this way. The only place the author would consider it dangerous to have solid joints on tramway rails laid in the usual method would be at the apex of a steep bridge such as one might meet over a canal or river, especially where there were long lengths of straight line on either side of the bridge, as under such circumstances it is quite possible that the rails might rise from the road-bed; but the prevention in this case is obvious, *i.e.*, leave the joints on the bridge unwelded, and, if possible, provide expansion joints.

APPENDIX.

Rail Electric Welding.—The number of joints electrically welded in Dublin is 4,300, the total number of fractures was five. These occurred not in the weld, but in the rail itself, and in each case through a hole in the web of the rail; these fractures always occurred shortly after the joints in the vicinity had been welded. It is now four months since the work was completed, and not a single fracture has occurred in this time.

Some of the welded track has now been in use for six months, and is giving great satisfaction under a three and a half to five minutes service; the running appears smoother than when the operations were first completed.

Power taken for Welding.—This in practice varies very much; if the trolley-wire pressure can be kept in or about 500 volts, the current taken is about 200 amps., but if the pressure falls below 450 volts and the reactance regulator in the welding car has to be used to keep the alternating volts up, the amount of direct current required increases very rapidly with the drop in volts, and I have noticed over 400 amps. being drawn from the trolley-wire, which itself tends to produce a drop of volts over the whole section.

Thermit Welding.—Although in this process the temperature produced in the rail is very high, trouble does not seem to have been experienced

from the subsequent softening of the head of the rail due to decarbonisation, as was the case in the early application of electric welding. This is explained by the fact that the rail when heated is not in the presence of oxygen ; the molten thermit is poured up in the mould right over the head of the rail excluding the air, the aluminium itself absorbing all oxygen present.

One important advantage thermit welding has over electric welding, is that being a fusion of metals the strength of the joint is independent of the welding qualities of the rail.

Cost.—The charge made for welding per joint on a contract of 2,000 joints is 25s. per joint. This includes the supplying of splicing bars, the polishing of the rail, etc., but not the cost of power, or the opening and relaying of the paving, lighting and watching, etc., which adds another 10s. per joint. Total, 35s. per joint.

The cost of the thermit for making a joint on a 100 lb. rail is about 20s., but the preparing of the joint is rather more costly than in the welding process, and probably works out at about 15s. per joint.

BIRMINGHAM LOCAL SECTION.

SOME PROPERTIES OF ALTERNATORS UNDER VARIOUS CONDITIONS OF LOAD.

By A. F. T. ATCHISON, B.Sc. Associate.

(*Paper read April* 20, 1904.)

In the following paper an endeavour has been made to point out some of the chief factors which govern the behaviour of alternators under different conditions which occur in engineering practice.

Intricate mathematical investigation has been avoided, and, as far as possible, only those theoretical questions discussed which have a direct practical bearing upon the subject.

A vast amount of scientific research has been carried out in connection with alternating current machinery during recent years, and the publications of such experimental and theoretical work have appeared continously in almost overwhelming numbers in the various technical periodicals of this, and more especially of other countries.

To a large number of engineers engaged in their professional work the greater part of these investigations must of necessity pass unnoticed, although the large amount of information which has been gained from such researches has been the means of enormously improving the design and construction of alternating current machinery, and rendering practicable the large enterprises which characterise electrical engineering of the present day.

In the majority of cases occurring in practice, alternators are required to supply current at an approximately constant terminal pressure, under loads which vary considerably in magnitude and in power-factor. Hence, one of the first points to be considered is the regulation of terminal P.D. which the machine will offer without excessive alteration of the excitation from outside. A similar problem occurs in the case of direct current machines, and introduces also the problem of sparkless commutation. Although in the case of the ordinary alternating current generator this latter difficulty is non-existent, the case, however, is complicated by the fact that the reactions taking place in the machine are not determined by the amount of current taken from the machine alone, but also by the phase relation of the current and E.M.F.

E.M.F. on Open Circuit.—When no current is being taken from the machine, the E.M.F. induced in the armature conductors is simply that due to their rotation through the magnetic field produced by the field

magnets themselves, and under no other circumstances can this identical condition exist. This E.M.F. will hereafter be referred to as the *nominal* induced E.M.F.

Since the angular velocity of the armature may be considered uniform, the E.M.F. induced in each armature wire on open circuit

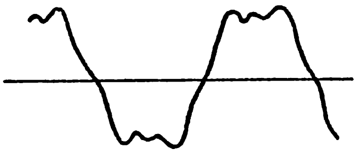


FIG. 1.

would represent by its wave-form the flux distribution under these circumstances, neglecting such secondary effects as to-and-fro pulsations of bands of flux which might be produced by the rotation of a toothed armature. But actual armature windings consist not of a single conductor, but coils, whose sides cut the flux successively, and the E.M.F. induced therefore between the extremities of such a coil is proportional at any instant to the time rate at which the flux enclosed by the coil is changing. Moreover, if the winding is not of the "concentrated" type, but has the conductors forming the sides of the coils more or less distributed, the E.M.F. induced will involve the vector sum of a number of separate E.M.F.'s differing more or less in phase according to the extent of the distribution of the winding.

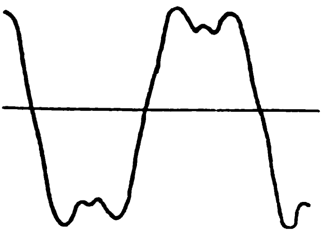


FIG. 2.

Such effects are taken into account when calculating the E.M.F. of a machine by the introduction of "breadth co-efficients."

The E.M.F. wave-form of the complete armature on open circuit will clearly be affected by any alteration in the flux distribution, and as an interesting example of this are shown two oscillograms of the open circuit E.M.F. wave-forms of the same alternator; Fig. 1 being that corresponding to a moderate excitation, and Fig. 2 corresponding to a powerful excitation, the difference in form being due to the change in permeability in different regions of the flux, owing to the difference in degree of saturation.

The next point to be considered is the E.M.F. induced in the armature when the machine is running under load.

E.M.F. Induced with Machine Loaded.—Directly there is current flowing in the armature the above conditions are altered, since the conductors are no longer rotating in the field produced solely by the field magnets; and it is important to consider carefully what conditions exist when the armature is carrying current. The flux which usually exists at any instant will be the resultant of those produced by all the M.M.F.'s which may be acting.

Now the M.M.F. due to the armature current will give rise to a flux of which the greater part (if the reluctance of the Leakage path be high) will traverse the same magnetic path as the flux produced by the M.M.F. of the field current, and may be considered to combine with this flux to form a resultant flux. This part of the effect of the armature current represents "True Armature Reaction." Now there is also a portion of the flux produced by the armature current which will leak along the air-gap and link with the armature conductors without traversing the path of the field magnet flux. This flux gives rise to what may be called the "Leakage Self-induction" of the armature, and should be carefully distinguished from the flux "linked with the armature when carrying unit current," since, as just considered, the greater part of the flux contained in this definition is already taken into account by the consideration of armature reaction.

Thus it is the final resultant of the several fluxes which gives rise to the actually induced E.M.F. in the armature conductors as they rotate.

It is thus clear that the actual or "real" E.M.F. induced in the armature conductors when carrying current is that due to the field magnet flux (modified by the true armature reaction) and the E.M.F. of true leakage self-induction; and hence at every instant this "real" induced E.M.F. is given by adding the simple resistance drop to the P.D. across the terminals of the machine at that instant.

Since in practice the armature resistance is always kept so low that the drop of pressure due to this is very small, it is clear that the effects of armature reaction and leakage self-induction will be the controlling factors in the regulation of an alternator, *i.e.*, the alteration of terminal P.D. with various current outputs (excitation constant).

The first point to be considered in this connection is the effect of armature reaction with various phase relations of armature current and E.M.F.

Considering first the case when the armature current is in phase with the nominal induced E.M.F., it is clear that in this case the current reaches its maximum when the armature coil is in a position midway between two field poles as shown in Fig. 3, since the rate of change of the flux through the coil is then a maximum, and passes through its zero value when the armature coil is immediately facing a pole; further, it will be seen that the effect of the armature current in this case is merely to increase the flux in the edge of the pole from which the coil is receding and to decrease it in the side of the pole which it is approaching. (In the case of a synchronous motor clearly the reverse will take place, since the current flows against the induced E.M.F.). Hence, with the current in phase with the induced E.M.F.

there is no weakening or strengthening of the field as a whole, but merely distortion—if we neglect the increase of reluctance due to the greater saturation of the one side of the pole piece, which effect might be slightly in excess of the corresponding decrease of reluctance in the other side.

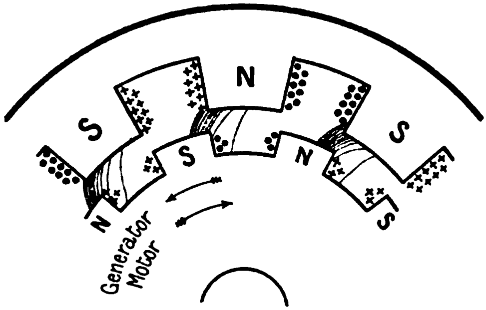


FIG. 3.—Cross-magnetising Effect.

Similarly, if we consider a current lagging behind the nominal E.M.F., then, since the current will not have reached its maximum value until the armature coil is partly facing the next pole, it will readily be seen from Fig. 4 that a "Demagnetising" effect is produced (and a magnetising effect in the case of the synchronous motor), and the field as a whole is weakened.

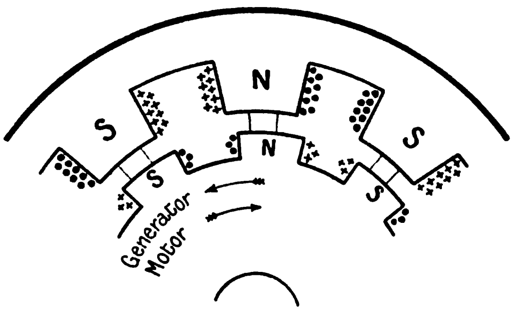


FIG. 4.—Demagnetising Effect { Lagging current in generator. Leading current in motor.

Similarly with the current in advance of the E.M.F. the generator field will be strengthened and the synchronous motor field weakened.*

* This conception of the field being as a whole strengthened or weakened by armature reaction was brought forward by Swinburne (*Journal Institution of Electrical Engineers*, vol. xx.), who pointed out that if the idea of the armature only possessing self-induction were correct, very large alternating E.M.F.'s would be induced in the field winding.

Such effects had been noticed by Dr. Hopkinson (Royal Soc., *Philo.*

As an illustration of field distortion on a non-inductive load, Fig. 5 shows the P.D. wave of an alternator (current wave is shown also, and is in phase with the P.D.). The distortion will naturally be less with a more strongly excited field, as is shown by Fig. 6—*cf.* with Fig. 2, which shows the open circuit wave of the same machine.

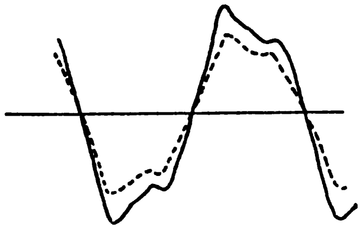


FIG. 5.

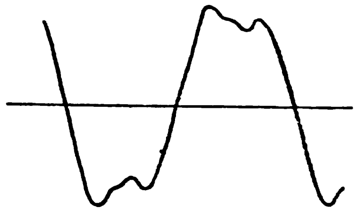


FIG. 6.

The effect of an almost wattless lagging current in weakening the field is shown in Fig. 7.

Even with a non-inductive load, *i.e.*, with a current in phase with the terminal P.D. of the machine, the current will lag behind the nominal induced E.M.F. owing to the self-induction of the armature itself, and hence, even on non-inductive load, the field is slightly weakened.

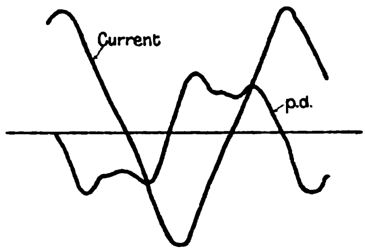


FIG. 7.

Considering now the true self-induction of the armature or armature leakage reactance, as was pointed out above, it is of the nature of a true self-induction, and the E.M.F. induced thereby will be in quadrature with the current, and hence with a lagging current will have a component in opposition to the nominal induced E.M.F., and in the case of a leading current, a component in conjunction with it.

Trans., 1896), in a machine of early design, but not sufficiently large to justify the consideration of armature self-induction and nothing more.

On examining the Fynn Inductor Alternator (used in some of the experiments which are described below) for pulsations of the field current or of the P.D. across the field winding, no such pulsations were perceptible even with the aid of the oscillograph.

In the case of a polyphase machine any pulsations in the field system would be still smaller, since the total armature reaction—due to the instantaneous effects of all the phases—is more nearly constant.

Thus armature reaction and leakage reactance have a similar effect, and since they always exist conjointly it becomes convenient to consider them together and represent the combined effect by the term "Synchronous Reactance"* of the armature.

It is evident that this is not a true reactance, since it includes the effect of armature reaction and of leakage reactance; and, in general, is different numerically from the value which is obtained by passing an alternating current of known frequency through the armature when at rest.

If we denote the Synchronous Reactance by p L and combine with it the resistance R of the armature, we obtain $\sqrt{R^2 + p^2 L^2}$, the important expression which may be termed the "Synchronous Impedance" of the Armature.

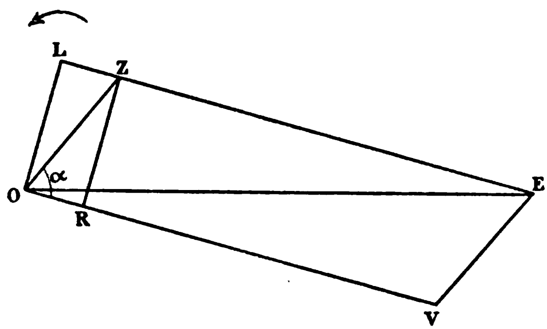


FIG. 8.

To obtain the value of this experimentally the simplest method is as follows:—

Obtain (1) a curve connecting the E.M.F. induced on the open circuit (the "nominal" induced E.M.F.) with the field current at constant speed.

(2) A curve connecting the field current with the corresponding values of the current obtained on short-circuiting the armature through a non-inductive ammeter.

The first of these curves is usually known as the "open-circuit characteristic," and will be of the form of a magnetisation curve, but with the "knee" more rounded off—since, in general, the various portions of the magnetic circuit will become saturated in succession. The second curve, or "short-circuit characteristic," will be usually a straight line for the greater part of its length.

Then if at any excitation the value of the nominal induced E.M.F. be divided by the corresponding short-circuit current, the quotient is the value of the Synchronous Impedance of the armature at that excitation.

* The term "Synchronous Reactance" was originally used by Steinmetz, and is now largely employed, especially by American writers.

The Synchronous Reactance may then be calculated when the resistance is known, thus

$$p^2 L^2 = Z^2 - R^2,$$

or

$$p L = \sqrt{Z^2 - R^2}$$

where Z = Synchronous Impedance found as above.

On the basis, then, of a definite armature impedance, it is possible to predict the regulation of the machine on loads of different power-factor.*

Representing the quantities by vectors, and then expressing the results analytically, appears the clearest way of gaining an insight into the problem.

(A) Non-inductive load (Fig. 8).

Draw from O, O R and O L at right angles representing in magnitude the quantities R I and pL I respectively, their vector sum O Z then represents the E.M.F. consumed by the impedance of the armature. Since the load is non-inductive the P.D. will be in phase with the current, and hence the P.D. vector will be in the same direction as O R, and since it is the vector difference of the E.M.F. (O E) (whose length is known from the open-circuit characteristic) and the E.M.F. consumed by the impedance, the triangle O Z E may be constructed, Z E being parallel to O R.

Putting

$R\hat{O}Z = \alpha$ (determined solely by the constants of the armature and not by the load),

it is now possible to determine the value of the P.D. V in terms of the current I.

Thus from the figure

$$OE^2 = OV^2 - VE^2 - 2\,OV.VE \cos O\hat{V}E$$

or

$$E^2 = V^2 + I^2 Z^2 + 2\,V.I.Z. \cos \alpha$$
$$= V^2 + I^2 Z^2 + 2\,V.I.R.$$

$$\text{since} \quad \cos \alpha = \frac{R}{Z}$$

Hence, solving for V

$$V = \sqrt{E^2 - p^2 L^2 I^2} - RI \quad . \quad . \quad . \quad . \quad . \quad (1)$$

This equation enables us to predict the terminal P.D. V of the machine when working on a non-inductive load, corresponding to various current outputs I.

This curve is only a particular case of the general equation to the regulation curves of the machine working under a load of *any* power-factor, which we shall now derive.

(B) General case, load of power-factor cos θ, where θ = phase difference between current and P.D.

* This method was originally given by Dr. Behn-Eschenburg (*Electrician*, July 26, 1895).

The vector diagram in this case is shown in Fig. 9, and is constructed as follows :—

O R and O L are drawn at right angles as before, representing the quantities R I and pL I, the E.M.F.'s consumed by the resistance and synchronous reactance respectively, giving the resultant O Z, the synchronous impedance E.M.F.

O V is drawn differing in phase from R I by the angle θ, cos θ being the given power-factor of the load. The length of O E the open circuit E.M.F. is known, and hence the point V is determined by constructing the triangle O V E in which V E is equal and parallel to O Z.

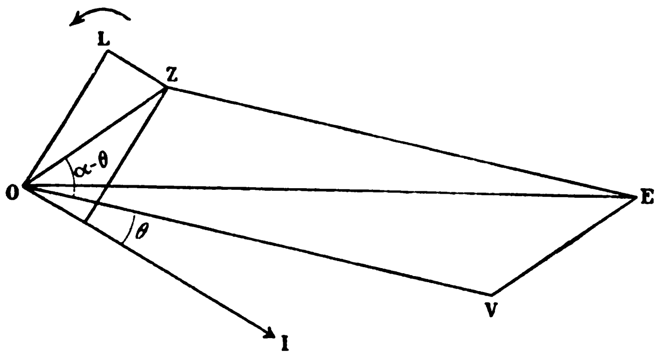


FIG. 9.

The general equation to the Regulation Curve of the machine working under any load of power-factor cos θ may be readily determined from this diagram ; thus from the figure

$$V^2 = E^2 - I^2 Z^2 - 2\ V.I.Z.\cos(a - \theta);$$

$\therefore$ solving for V,

$$V = \sqrt{E^2 - I^2 Z^2 + I^2 Z^2 \cos^2(a - \theta)} - I Z \cos(a - \theta)$$

$$= \sqrt{E^2 + I^2 Z^2 \left\{\cos^2(a - \theta) - 1\right\}} - I Z \cos(a - \theta)$$

$$= \sqrt{E^2 - I^2 Z^2 \sin^2(a - \theta)} - I Z \cos(a - \theta)$$

$$= \sqrt{E^2 - I^2 Z^2 (\sin a\ .\ \cos\theta - \cos a\ .\ \sin\theta)^2} - I Z (\cos a\ .\ \cos\theta + \sin a\ .\ \sin\theta).$$

Now $$\sin a = \frac{p\,L}{Z}$$

and $$\cos a = \frac{R}{Z},$$

$$\therefore V = \sqrt{E^2 - I^2 (p\,L\cos\theta - R\sin\theta)^2} - I\,(R\cos\theta + p\,L\sin\theta)\ . \quad (2)$$

which is the general equation to the regulation curve. Equation (1) derived above is clearly a particular form of this general equation when the parameter θ is put equal to zero.

On the basis, then, of the quantity "Synchronous Reactance" found from the open and short-circuit characteristics, the regulation of the machine may be predicted from the equation just given. The question whether or not the results thus obtained, using the value of synchronous impedance given by the short-circuit curve, are to be relied upon as agreeing with those actually obtained by experiment has been investigated in the experiments described below.

It may be as well to point out again that the Synchronous Reactance is a fictitious quantity, and as such it has no physical existence, but is taken to represent numerically the equivalent of a true reactance (in ohms) which the armature may be considered as possessing. This

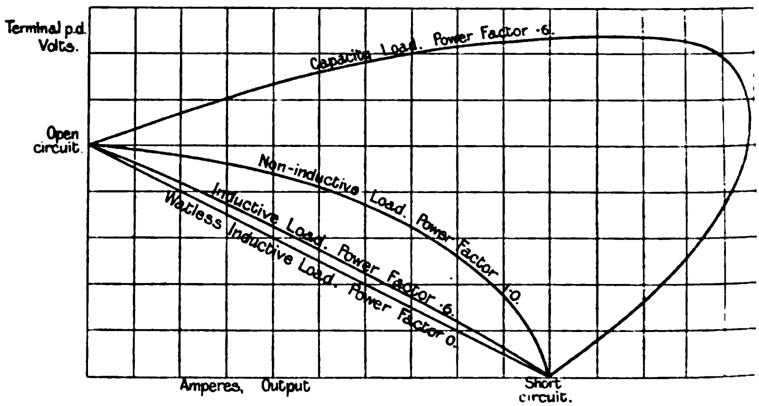


FIG. 10.—Theoretical regulation curves on loads of different power-factor.

value may then be employed as shown above in the construction of vector diagrams of E.M.F.'s, etc.

The separate effects armature reaction and leakage inductance are thus conveniently combined into a single quantity.

It is to be regretted that this point appears to be overlooked in many articles dealing with the subject of alternators—the armature generally being regarded as possessing a simple coefficient of self-induction and nothing more.

In recent American works, however, the term is now widely employed and calls for no further comment.

Before giving the results of some experiments on the subject, it is proposed to examine some important properties of alternators which may be deduced from the above considerations.

The general equation (2) above represents a family of ellipses with the variable parameter θ, and the graphs (Fig. 10) show that the P.D. V falls off much more rapidly on inductive loads (θ positive) than on non-inductive ones ($\theta =$ zero) and may *increase* at first on a capacity load or one taking a leading current, *e.g.*, over-excited synchronous motors

and converters (θ negative). This is of course of the greatest importance in connection with alternating current supply; loads of low power-factor rendering it difficult or even impossible to maintain a constant pressure at the station. The self-excitation and compounding of alternators and devices for improving the power factor of induction motors and other developments in this direction are methods to be anticipated in the practice of the near future.

The subject of the regulation curves and derived curves of power, apparent watts, etc., lends itself to an unlimited amount of mathematical development, but since only a small part of the various curves

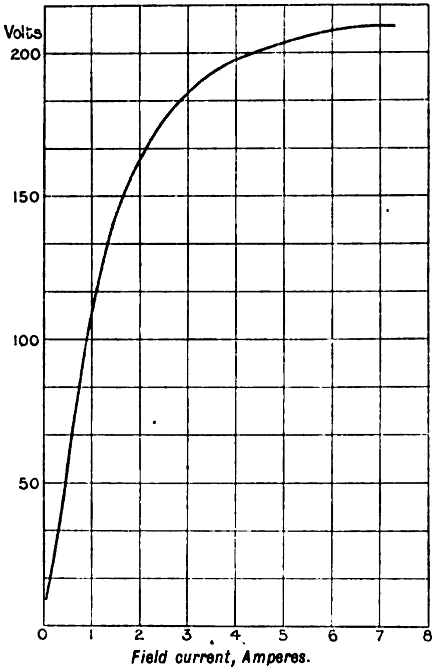


FIG. 11.—Open-circuit characteristic of Machine A.

is available in practice—owing to the full load current being reached at a comparatively early stage, it is not proposed to dwell further on that aspect of the subject.*

As an illustration of the theoretical regulation curves of an alternator calculated from the above equations on loads of various power-factors,

* This point is especially noticeable in connection with synchronous motors and the closely allied subjects, where many interesting points may be theoretically deduced about limiting values of excitation—maximum power—general conditions of stability, etc. The results, however, should be taken as merely representing in outline the nature of the phenomena and the inherent tendency of the plant, rather than conditions which would occur in engineering practice.

Fig. 10 shows the various curves from open to short circuit at constant excitation, *i.e.*, at constant "nominal induced E.M.F." It will be seen that at low power-factors the curves become more nearly straight lines and lie closer together, showing that for loads of very low power-factors the regulation is almost equally bad, but that for power-factors in the neighbourhood of unity the terminal P.D. is much more sensitive to changes in the power-factor of the load.

As mentioned above, it is only a small portion of these curves which can be obtained in practice from modern machines, as it is impossible to short circuit such machines when fully excited.

In the early types of alternators this might be done without a very excessive short-circuit current being obtained, owing to the

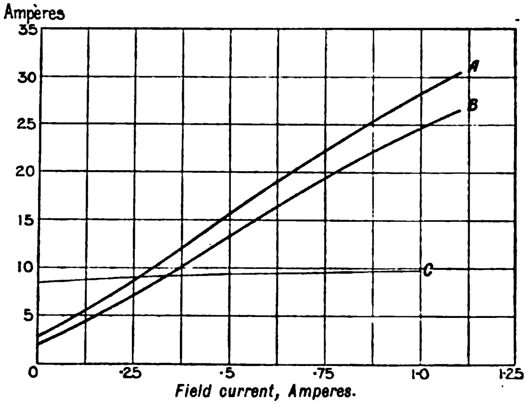


FIG. 12.—Short-circuit characteristics, Machine A.
Curve A, Single-phaser ; Curve B, Two-phaser.

large amount of "leakage reactance," and of armature reaction—in other words, owing to the high value of the synchronous reactance; whereas in machines of modern design, such as those used in the experiments described in this paper, the full-load current was obtained on short-circuiting the armature with the field only excited to a small fraction of the normal amount.

The question that arises in question with the regulation of alternators is, How closely will the curves calculated from the Synchronous Impedance agree with the regulation curves obtained from the machine in actual work?

Before discussing other methods of calculating regulation and armature reaction, the results are given of some experiments carried out by the writer to investigate the value of the quantity Synchronous Impedance as obtained from the open and short-circuit characteristics.

Four machines of different types were experimented on, viz:—

Machine A.—"Fynn" type of Inductor Alternator (2-phaser), by Johnson and Phillips. 5 k.w.

Machine B.—An old single-phase Inductor Alternator, by Pike, Harris & Co. 7 k.w.

Machine C.—E.C.C. 3-phaser of the "flywheel" type, with revolving fields. 6 k.w.

Machine D.—Fuller-Wenström with revolving armature (single-phaser). 12½ k.w.

In the following tests Machines A and C were run as single-phase machines, only one phase being loaded.

Machine A.—Tests on Fynn Type of Inductor Alternator.

The open-circuit characteristic at 50 ∿ per sec. is shown in Fig. 11, and the short-circuit characteristic in A, Fig. 12. From these value of the Synchronous Impedance is determined, which is approximately constant (C, Fig. 12).

The short-circuit current may be taken up to twice or three times the normal full-load current for a short time, in order to obtain that part of the curve which corresponds to as strong an excitation as possible.*

It may be noted that, as a matter of fact, in the determination of the open- and short-circuit characteristics, exact constancy of speed is not essential, since on open-circuit the E.M.F. is strictly proportional to the speed, for a given excitation, and the readings for the open-circuit curve can therefore be accurately corrected in proportion and reduced to the normal speed should it for any reason be impossible to maintain this perfectly constant throughout; and, secondly, the short-circuit current is practically independent of the speed through a very wide range of the latter for the following reason:—

Since the armature resistance is always small in comparison with the reactance term, the short-circuit current

$$I = \frac{E}{\sqrt{R^2 + p^2L^2}}$$

may be written

$$I = \frac{E}{pL}$$

of which both numerator and denominator are proportional to the speed.

In most instances, however, there will be no tendency towards variation in speed when these two curves are being obtained, since for open-circuit curve the machine is unloaded throughout (except for the iron losses, etc.), and in the case of the short-circuit characteristic the current is practically wattless, and hence little or no extra load is thrown on the prime mover.

In every case the speed and (if necessary) the exciting current were adjusted to the normal value before taking each reading on the regulation curve, the alternator being electrically driven, which facilitated

* The chief objection to this method of obtaining the Synchronous Impedance is here encountered, namely, that the value obtained must either be that corresponding to an abnormally weak field, or else to an abnormally large armature current; in other words, it is to be expected that the value obtained will be too large.

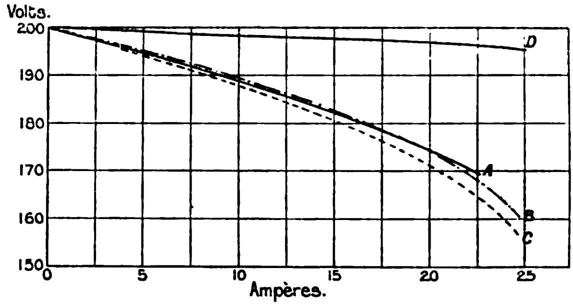


FIG. 13.—Regulation curves, Machine A. Cos θ = 1.

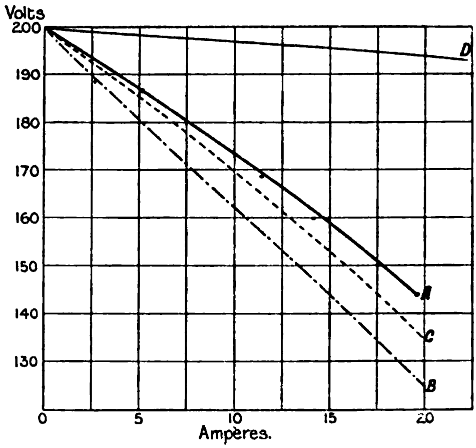


FIG. 14.—Machine A. Cos θ = 0·5.

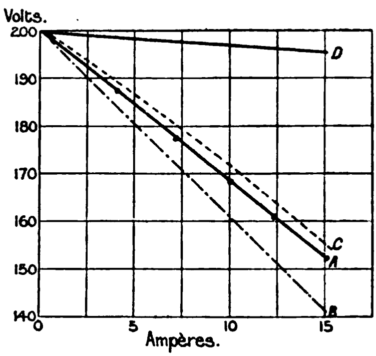


FIG. 15.—Machine A. Cos θ = 0·25.

exact speed regulation; and the fields being excited from a storage battery with a rheostat and accurate ammeter in circuit.

In Fig. 13 Curve B shows the regulation curve of the Fynn Inductor Alternator on a non-inductive load as predetermined from the open and short-circuit characteristics by the equation (1) and vector diagram explained above. Curve A is the actual regulation curve of the obtained experimentally with the machine working on a non-inductive load. (The normal full load current of the machine being 12·5 amperes per phase.)

In Fig. 14 Curves A and B represent as before the regulation curve of the machine working on an inductive load of power-factor 50 per cent, Curve A being obtained by experiment and Curve B calculated from equation (2).

In Fig. 15 are shown the corresponding curves for a load of power-factor 25 per cent.

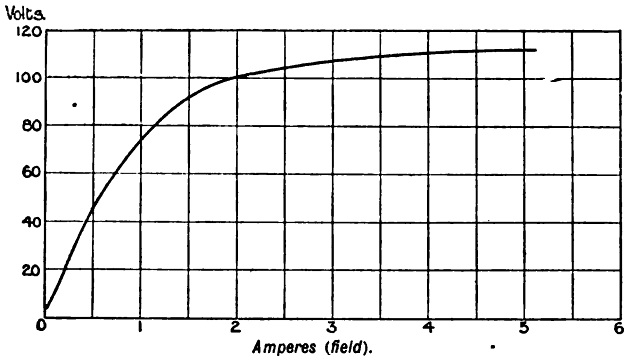


FIG. 16.—Open-circuit characteristic, Machine B.

Throughout these experiments the inductive load was made up of a number of coils of insulated wire without iron cores, the current being varied by suitable combinations of series and parallel grouping of the coils, the power-factor (calculated each time from the readings of the voltmeter, ammeter and Weston wattmeter readings) being kept constant throughout each test by suitably altering the mutual inductance of the coils by more or less superposing them on each other.

In this alternator it is seen that the curve calculated from the synchronous impedance lies in each case below the curve obtained experimentally, showing that the open- and short-circuit characteristics give too high a value for the synchronous impedance, *i.e.*, the machine is found to regulate considerably better than would be predicted by this theoretical method.

Machine B.—Old design of Pyke and Harris Inductor Alternator. —The open- and short-circuit characteristics at 85 ∿ per sec. are shown in Figs. 16 and 17.

Curve A in Fig. 18 is the actual regulation curve of the machine on

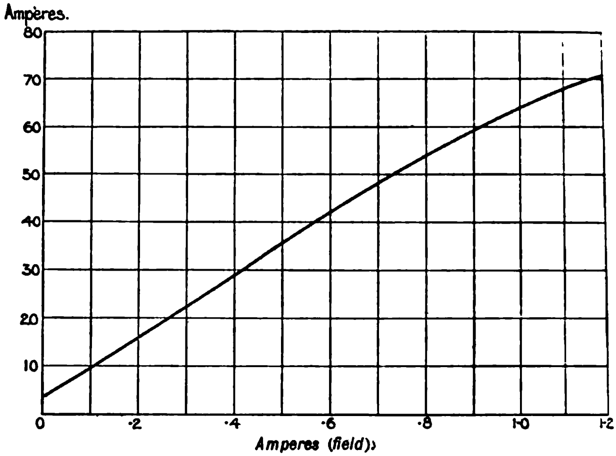


FIG. 17.—Short-circuit characteristic, Machine B.

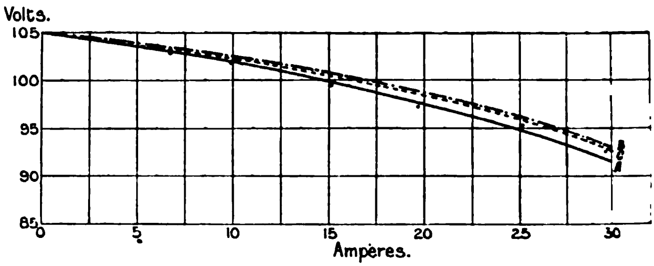


FIG. 18.—Machine B. Cos θ = 1.

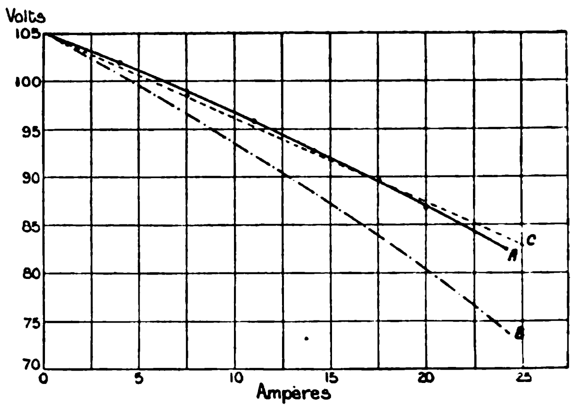


FIG. 19.—Machine B. Cos θ = 0·5.

a load of unity power-factor, and Curve B that calculated from the synchronous impedance.

In Fig. 19 Curves A and B are the same with the machine working on an inductive load of power-factor 50 per cent., and the corresponding Curves A and B (Fig. 20) are the experimental and calculated curves on a load of 35 per cent. power-factor.

In this machine the agreement between the theoretical and actual curves is remarkably close in the case of the non-inductive load, but on the loads of low power-factor the regulation is again considerably better than that predicted by the theoretical curves.

It is to be noticed, however, that the general form of all these curves is very similar to the theoretical series shown in Fig. 10, the curves at the low power-factors being less rounded and lying closer together.

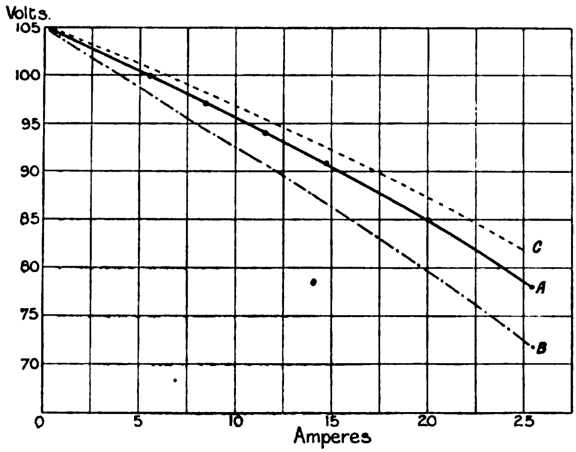


Fig. 20.—Machine B. Cos $\theta = 0{\cdot}35$.

Machine C.—E.C.C., Flywheel Alternator.—Open- and short-circuit characteristics are given in Figs. 21 and 22, at a frequency of 50 ∿ per sec. Fig. 23 shows the curves of this machine on non-inductive load, Curve A being the actual and Curve B the calculated curve.

The agreement in this case is very close.

Machine D.—Fuller Wenström Single Phaser, with revolving armature.—Figs. 24 and 25 are the open and short circuit curves at 50 ∿ per sec. This machine (considerably the largest of those tested) shows excellent regulation, having a drop of terminal voltage of only 4 per cent. from no load to full non-inductive load. In this case, too, the actual curve (A, Fig. 26) agrees extremely closely with the theoretical curve (Curve B).

From these tests it appears that the tendency is for the value of synchronous impedance, as calculated from the open- and short-circuit characteristics, to come out too large. As indicated above, this is due to the fact that, in so determining the value, the machine is working with a very much under-excited field or with a very excessive armature

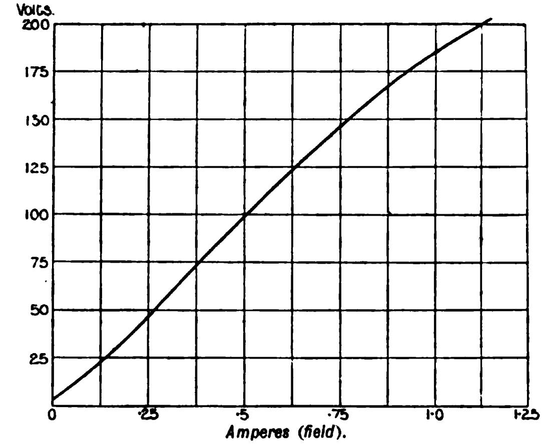


FIG. 21.—Machine C. Open-circuit characteristic.

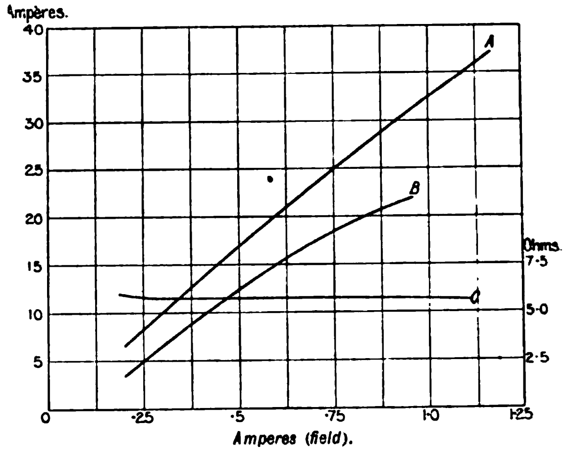


FIG. 22.—Machine C. Short-circuit characteristics {A as single-phaser. B as 3-phaser.
C, Synchronous impedance curve as single-phaser.

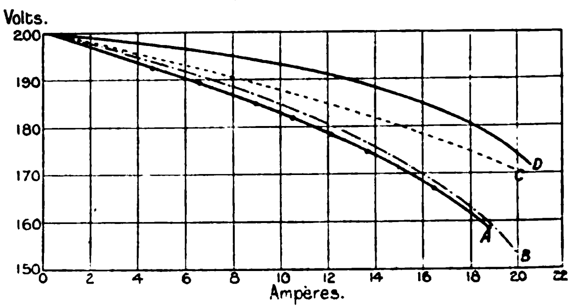


FIG. 23.—Machine C. Cos $\theta = 1$.

current, both of which circumstances would give rise to a larger amount of armature reaction than would occur under normal working conditions.

Further, since the short-circuit current is practically a wattless lagging current, its maximum value will occur when the armature coils are approximately under the pole pieces; and hence, as previously shown, the armature reaction will be still further exaggerated.

It has been suggested to overcome this objection by assuming that for an in-phase current the synchronous impedance is some fractional part (about ·7) of its value for a wattless lagging current, and assuming that it follows a straight line law for intermediate angles of lag; that is

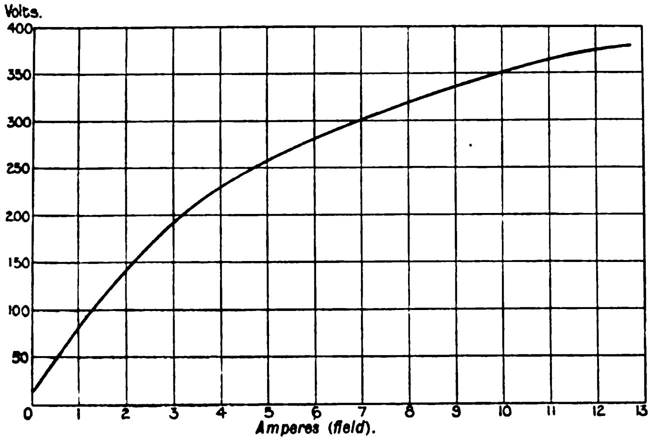


FIG. 24.—Machine D. Open-circuit characteristic.

to say, regarding the armature as possessing a different impedance for loads of different power-factor—an assumption which is undoubtedly nearer the truth.

Thus :—

An ingenious suggestion for estimating the effective impedance of the armature under more normal conditions is the following, due to Prof. Baum :—*

The machine whose impedance is to be measured is run as an unloaded synchronous motor, and its field excitation is increased until about the full load armature current is flowing (according to the well-known "V curves" of the synchronous motor); and then the algebraic difference between its "nominal" counter E.M.F. (obtained from the open-circuit characteristic) and the P.D. across the armature terminals will be almost exactly the E.M.F. consumed by the impedance.

If, then, this difference be divided by the armature current, the quotient may be taken as the effective armature impedance.

The reason is clear from the simple vector diagram of the E.M.F.'s (Fig. 27).

* *Electrical World and Engineer*, April 26, 1902.

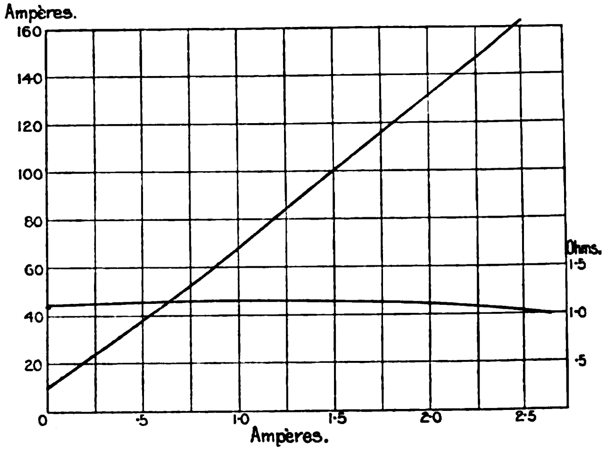


FIG. 25.—Machine D. Short-circuit characteristic and Synchronous impedance curve.

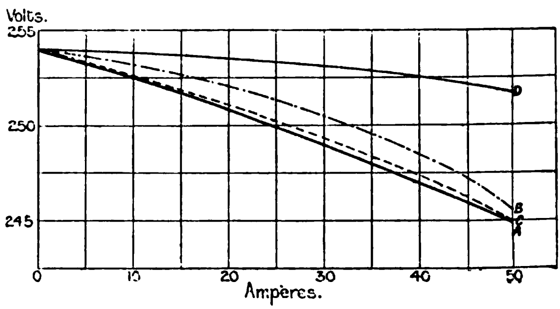


FIG. 26.—Machine D. Cos $\theta = 1$.

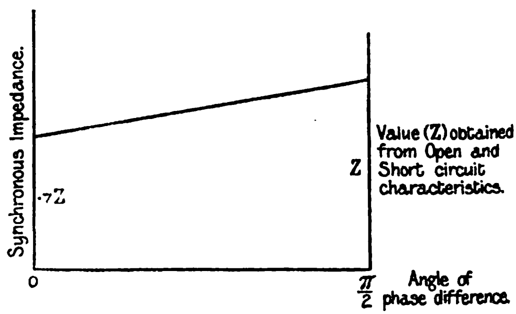


FIG. 26A.

O R is the ohmic drop in phase with the current, and therefore, since the motor is over excited, nearly 90° ahead of the impressed P.D. vector O V. O L is the E.M.F. consumed by the reactance, 90° ahead of O R, and combines with O R to give O Z the vector of impedance E.M.F. Hence the vector of counter E.M.F. O E is determined, and since the armature drop will always be small compared with O E or O V, it is clear that the counter E.M.F. O E will be very nearly in opposition to the impressed P.D. O V, and hence the algebraical difference may be taken with sufficient accuracy as representing the vector difference.

This method, again, is open to the objection that the machine is working with an *over*-excited field, and with a current about 90° behind its (counter) E.M.F.; and, further, it may not be always possible or convenient to run the machine as a synchronous motor.

Testing Machines *A* and *D* in this way, the values of the impedance work out to 4·6 and 2·7 ohms respectively (as compared with 3·9 and 1·1 found from the short-circuit method), which are excessive. The explanation of this is probably that the simple vector diagram of

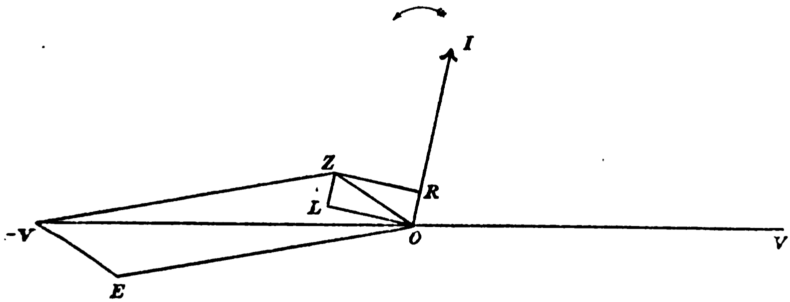


FIG. 27.

E.M.F.'s is not sufficiently near the true conditions to justify its use in this way when the two machines have such widely different wave forms* (*cf.* Figs. 2 and 58).

POLYPHASE MACHINES LOADED ONLY ON A SINGLE PHASE.

If the regulation of a polyphase machine symmetrically loaded be compared with that obtained when only loaded on one phase, the pressure-drop in the former case will be found to exceed that in the latter. This would be expected from the fact that the armature reaction is increased by the presence of the current in the other phases. In other words, the synchronous impedance as a polyphaser should be greater than as a single phaser.

* Unless the wave form of the motor is approximately of the same form as that of the generator, it is probable that the additional accuracy might be lost, owing to the extra cross currents between the machines.

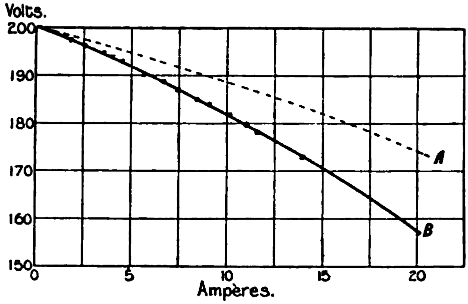


FIG. 28.—Comparison of single- with polyphase regulation. Curve A, Machine A as single-phaser ; Curve B as 2-phaser.

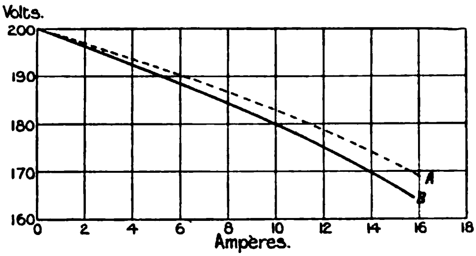


FIG. 29.—Comparison of single- with polyphase regulation Curve A, Machine C as single-phaser ; Curve B as 3-phaser.

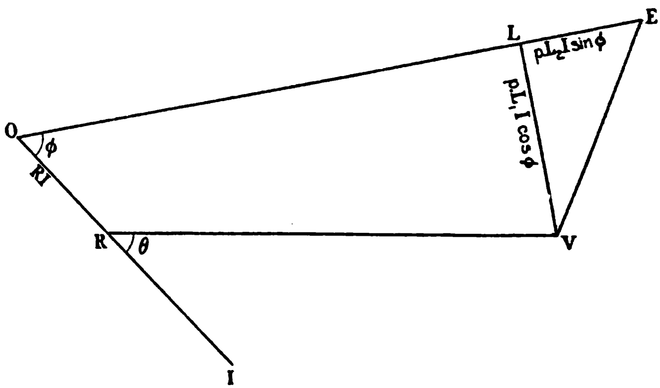


FIG. 30.—Blondel's Diagram.

Testing Machines A and D as a 2-phaser and 3-phaser respectively, this is found to be the case. The short-circuit current in each phase when simultaneously short-circuited being less than that obtained on short-circuiting one alone, at the same excitation (Figs. 12 B, 22 B), thus giving a higher value for the synchronous impedance.

The regulation of Machine A loaded on both phases is shown in Fig. 28 and that of Machine D loaded on all three phases is shown in Fig. 29.

Comparison with the corresponding curves when the machines were used as single phasers (*cf.* Figs. 13 A and 23 A) shows an increase of pressure drop as would be expected.

Also in a 2-phaser the total reactive ampere-turns of the armature will not fluctuate so much as in a single-phase machine, and in the case of a 3-phase armature the sum of the ampere-turns will be still more nearly constant.

Since the conception of an alternator armature possessing an

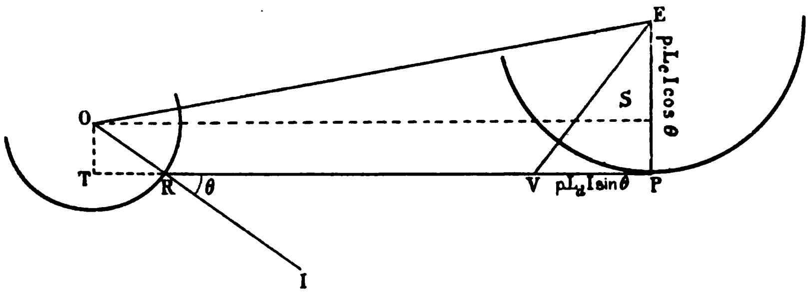


FIG. 31.—Author's Method.

inductance which can be represented by a single term is necessarily an assumption which may in many cases lead to considerable discrepancy with actual results, the subject has received a large amount of attention during the development of alternating current working; and many other methods of treating the subject of armature reaction have been proposed.

It was shown at the beginning of this paper that the effect of armature reaction upon the field was a twofold one, namely a *cross-magnetising* effect due to current in phase with the "nominal" induced E.M.F. and a direct *demagnetising* effect produced by an out of phase current.

From these considerations Blondel* suggested that accurate results might be obtained by assuming two components of the reactance drop, corresponding to the power and idle components of the current.

The E.M.F. $pL_1 I \cos\phi$ (proportional to the load component of the current) being considered as in quadrature with the E.M.F. representing the cross-magnetising effect, and the E.M.F. $pL_2 I \sin\phi$ (pro-

* *Comptes rendus*, Oct. 16, 1899.

portional to the idle component of current) being in opposition to the E.M.F., and representing the loss of pressure due to the demagnetising action of the wattless components of current.

Or expressed by a vector equation, the terminal P.D.

$$\overline{V} = \overline{E} - \overline{RI} - \overline{pL_1 I \cos\phi} - \overline{pL_2 I \sin\phi}$$

where E is the nominal induced E.M.F., and ϕ the angle between this and the current.

The vector diagram takes the form of Fig. 30 : O E being the nominal induced E.M.F. and O I the direction of the current differing in phase from O E by the angle ϕ ; O R = R I the resistance drop in phase with O I ; E L the drop due to the demagnetising component, and L V the equivalent of the cross magnetisation.

The terminal volts are then given by the vector R V differing in phase from the current by the angle θ, where $\cos\theta$ is the given power-factor of the load.

It will be noticed that this method is more general by the introduction of two different coefficients of self-induction L_1 and L_2 corresponding to the load and idle components of the current.

The angle ϕ, however, cannot be readily measured experimentally, since the power-factor of the load is given by $\cos\theta$ and not by $\cos\phi$.

To obviate this difficulty and to make the problem more directly determinate the writer suggests the following method :—

Consider the fall of pressure to be due to the three components

R I in phase with I,
pL_d I $\sin\theta$ in phase with V the terminal P.D. and
pL_c I $\cos\theta$ in quadrature with V,

then, since $\cos\theta$ is the known power-factor of the load, the diagram. which takes the following form, is readily determinable.

The two coefficients of Inductance L_d and L_c may be found as described below.

To find the terminal volts V corresponding to a current I of power-factor $\cos\theta$.

Take a line O E (Fig. 31) representing the open circuit or nominal E.M.F. and from O describe a circle with radius O R = R I

and from E describe a circle with radius E P = $p L_c$ I $\cos\theta$

a tangent R P to this latter circle is then drawn from a point R on the first circle such that

$$\text{angle } ORP = \pi - \theta$$

from P R is then subtracted P V = pL_d I $\sin\theta$

representing the volts lost through the demagnetising component, and the vector R V then gives the required terminal voltage.

In this diagram the only angle required to be known is θ, which is given by the power-factor of the load ; the components of the current in phase and in quadrature with the *terminal* P.D. V being considered instead of those in phase and in quadrature with the E.M.F. as in the original method of Blondel.

The angle ϕ (Fig. 30) which cannot be readily determined is thus eliminated from the construction.

The relation between the terminal voltage and the current on a load of any power-factor ($\cos \theta$) may be expressed analytically from the diagram.

Thus, drawing O S parallel to R P and completing the rectangle O S P T and joining O P, we have

$$S O^2 = P T^2 = O E^2 - E S^2$$
$$i.e.\ (P R + R T)^2 = O E^2 - (E P - S P)^2$$
$$(P R + R T)^2 = O E^2 - (E P - O T)^2$$
$$i.e.\ (V_t + pl_d I \sin \theta + R I \cos \theta)^2 = E^2 - (pl_c I \cos \theta - R I \sin \theta)^2.$$

In order to find the components of the reactance, the armature is fixed (*a*) with the coils immediately facing the field poles, and (*b*) with the coils midway between two adjacent pole pieces, and then with the *field excited to its normal value* an alternating current of the given frequency is passed through the armature, and the P.D. across the terminals, and the corresponding current and noted, the quotient giving the impedance for the two positions, from which can be at once determined the two values of the reactance.

The armature in position—

(*a*) giving pL_d, the reactance corresponding to the *demagnetising* component,

and (*b*) giving pL_c, the reactance corresponding to the *cross* magnetising component.

It is important that the measurements be carried out with the field excited, as the inductance is considerably less in this case than with the field not excited, owing to the decrease of the permeability with saturation.

As an instance of this, the values of L_c and L_d in the case of the Pyke and Harris Inductor Alternator were reduced in the ratio of 100 to 67 and 100 to 92 respectively when the field was excited; and a similar result was obtained with all the other machines.

It will be noticed that in this way the reactance of the armature is obtained with both field and armature currents of normal values,* and hence the fundamental objection to the open- and short-circuit characteristics method is obviated.

If instead of clamping the armature it be rotated by an external source (the field, of course, not being excited), the quotient of the P.D. by the current works out to be almost exactly the arithmetic mean of the two values of the impedance for the armature in the two fixed positions, as would be expected; but if the speed be adjusted so as to run the armature very nearly in synchronism with the frequency of the generator supplying the current, the difference in the value of the reactance for different relative positions of armature and field poles is very clearly shown by "beats" or pulsations of the ammeter and volt-

* If necessary various values of the reactance can be obtained corresponding to different armature currents, but with an excited field the reactance is practically independent of the armature current, as the saturation of the magnetic circuit is not disturbed sufficiently to change the permeability to any serious extent.

meter corresponding to the difference of the frequency of the two machines, the ammeter reader increasing when the voltmeter decreases and *vice versâ.*

(This effect is totally distinct from the large pulsations which occur when "synchronising" alternators or synchronous motors, in which case *both* the machines are excited, and the voltmeter is connected across the two machines in *series*, and the switch between them still being *open*.)

So far as the writer is aware, this effect has not been previously noticed, and it demonstrates very clearly the change in the reactance of the armature, with change of relative position of the armature coils and fixed poles.

The regulation curves of the four alternators experimented upon have been calculated graphically by this "double reactance" method, and are shown by the curves C, in Figs. 13, 14, 15, 18, 19, 20, 23 and 26. It will be seen that in nearly every case the agreement between the curves calculated in this way, and those obtained by experiment (curves A) is remarkably close, and coincide more nearly than those obtained by calculation from the open- and short-circuit characteristics.

By drawing the vector diagrams to a fairly large scale an accuracy at least equal to that obtainable in the actual tests can be relied upon, as in other graphical solutions.

Having considered some methods by which the regulation of alternators may be predetermined theoretically by the vectorial combination of E.M.F.'s, it remains to investigate another class of solution of the problem, which consists in combining vectorially not E.M.F.'s but M.M.F.'s or ampere-turns.

This method of dealing with the question was first proposed by Rothert,* and has since been dealt with by many other writers, including Fischer-Hinnen, Potier, Picou, and Arnold. The method undoubtedly has the advantage of investigating more closely the actually existing conditions in an alternator, and has been used to a considerable extent by designers.

As in the first method considered the open- and short-circuit characteristics of the machine are supposed to be known; and it is then necessary to consider the magnetic flux which exists when the alternator is short-circuited with its full armature current flowing.

What was termed the "real" E.M.F. induced in the armature under these conditions is simply that required to overcome the ohmic drop and may be represented by a vector of direction O R, and the flux inducing this may therefore be represented by a vector O Y in quadrature with it. Further, the short-circuit current itself produces the flux of leakage self-induction, which may therefore be represented by O X in phase with O R, the resultant O Z of the fluxes O X and O Y therefore gives the flux which exist in the armature under these conditions.

This actually existing flux must be due to the resultant of the M.M.F.'s acting, namely, the field ampere-turns, and the armature ampere-turns, and hence the following diagram of ampere-turns may be drawn.

* *Elektrotechn. Zeitschr.*, Aug. 31, Sept. 7 and 14, 1899.

From the open circuit characteristic may be found the ampere-turns required to produce the flux O Z (the speed and number of armature conductors, etc., being known); and, therefore, by altering the scale of the diagram, the line O Z may be taken to represent these ampere-turns. From Z is then drawn the vector Z A parallel to O X, equal in magnitude to the ampere-turns of the armature, and the closing side O A of the triangle represents the ampere-turns of the field when full load short-circuit current is flowing.

Conversely, if the leakage flux is not known in the first instance, A Z representing the armature ampere-turns may be drawn, and a circle with radius A O = field ampere-turns described about A as centre, and the right-angled triangle O Y A may then be constructed, the length O Y, the ampere-turns for the ohmic drop being known from the open-circuit characteristic.

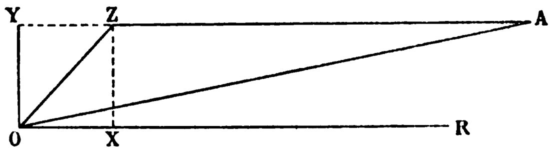


FIG. 32.

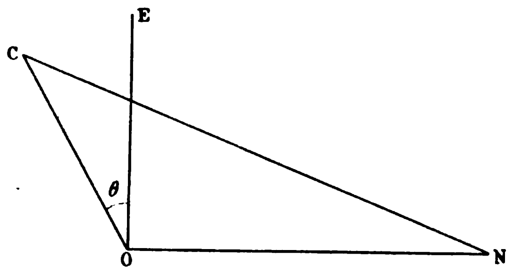


FIG. 33.—Rothert's Method.

Since in practice the resistance drop is very small, the vector O Y is small, and O A may be considered approximately equal to Y A, and hence it follows that on short-circuit the field ampere-turns are practically equal to the sum of the armature ampere-turns and those corresponding to the leakage self-induction.

When the alternator is supplying current to an external circuit under a definite terminal pressure, a similar combination of M.M.F.'s may be made by considering the field ampere-turns to be employed—

(*a*) in driving the current through the armature itself,
and (*b*) in maintaining the given terminal pressure.

Of these the first is known from the short-circuit characteristic, and the second from the open-circuit characteristic of the machine.

The vector diagram is then as Fig. 33, O E being the phase of the E.M.F., O N, in quadrature with it, represents the ampere-turns for

the flux required to induce it, and is obtained from the open-circuit curve; O C lagging by the angle θ (where cos θ is the power-factor of the circuit) represents the armature ampere-turns, and O N, the closing side of the triangle, gives the ampere-turns on the field in order that the terminal pressure be maintained. Or, conversely, to find the P.D. for any excitation and load, a line in the direction O N is drawn, and differing in phase from this by the angle θ, a line representing the ampere-turns found from the short-circuit curve, and then with C as centre and a radius equal to the field ampere-turns, an arc is described cutting O N in N, and O N then gives the ampere-turns available for maintaining the terminal pressure, which latter is then found by referring to the open-circuit characteristic.

It should be noticed that this vector diagram is not strictly correct, as it assumes that the ampere-turns consumed by the armature itself are in phase with the armature current; or, in other words, that the vector O A (in Fig. 32) lies along A Y, since the ampere-turns O Y (Fig. 32) required to overcome the ohmic resistance of the armature are very small, the angle O A Y is not more than about 10° in modern machines, and hence the neglect of armature resistance in Rothert's diagram may be corrected for by making the angle E O C exceed θ by about 10°; or, as an alternative, the E.M.F. may be considered as necessarily to be increased by an amount equal to the component of the resistance-drop along it; that is, C N may be taken as the ampere-turns required to induce

$$E + R I \cos \theta \text{ volts.*}$$

As might be expected, the tendency of the simple vector diagram of Rothert is to calculate better regulation for an alternator than that which is found by experiment to occur, although by the selection of suitable constants coefficients which may be obtained by tests on different types of machine (such as to take into account, for instance, the increase of field and armature leakage at full load), the diagram has found a wide use at the hands of designers.

This method, in particular, is not satisfactory in the case of single-phase machines, as the ampere-turns of the armature, being alternating, might be considered as incorrectly estimated if the R.M.S. value of the current is considered in connection with their reactive effect on the field. For this reason the introduction of another coefficient, depending on the wave form, would be necessary.

Without the use of these arbitrary corrections, the simple vector diagram gives values for the terminal voltage considerably in excess of those that are obtained by experiment, as is shown by the regulation curves D, which have been calculated by Rothert's diagram.

In this respect the method has the opposite effect to that of the open- and short-circuit curve method of Behn-Eschenburg which, as was seen, tends to predict worse regulation than the machine possesses.

Methods following the lines suggested by Blondel appear in general

* In order to allow for the reactive effects of eddy-currents in the pole faces, it is better to add about twice this, or $2 R I \cos \theta$.

to lead to results nearest the truth—a conclusion which has been arrived at independently by several investigators.

The subject of Armature Reaction in Alternators has received an enormous amount of attention throughout the progress of alternating current working, and to describe and examine in detail the methods of the numerous workers in the subject would result in a collection of side issues, each of which, however, has been found in certain instances to possess individual merits of its own.

Among the chief methods of dealing with the problem, however, may be mentioned :—

(*a*) That of Fischer-Hinnen,* who suggests a diagram similar to that of Blondel, but combining (as in Rothert's method) not E.M.F.'s but ampere-turns.
(*b*) That of Seefehlner,† who introduces the leakage coefficient into a diagram of ampere-turns.
(*c*) A recent mathematical treatment by Prof. Guilbert,‡ treating the question from dimensions of pole faces, slots, and other constructional details.
(*d*) A "two reactance" method, based on the method of Blondel, by Prof. L. A. Herdt,§ described in a recent paper, and amply verified by experimental results.
(*e*) The treatment by Gisbert Kapp,‖ dealing mainly with the virtual diminution or change in the effective ampere-turns of the field.

Compounding of Alternators.

As has been seen above, at constant excitation, the terminal voltage of an alternator will fall to a greater or less extent with increasing load. In order to remedy this defect, attempts have been made since the early days of alternator construction to apply to the alternating generator the principles of *compounding* as met with in the case of direct current machines.

In view of recent developments in connection with commutator alternators, it may not be out of place to briefly recapitulate in outline some of the earlier methods of compounding alternators, which although never particularly favoured in this country, have been in vogue to a considerable extent in American practice.

To increase the excitation with increase of load, it is necessary to rectify the whole or a fraction of the armature current and pass it in this condition through a separate series or compounding winding on the field magnets.

* *Elektrotechn Zeitschr.*, Dec. 26, 1901, and *Zeitschr. Elektrotechn.*, Wien, Jan. 19 and 26, 1902.
† *Zeitschr. Elektrotechn.*, Wien, Sept. 16 and 23, Oct. 21, 1900.
‡ *Electrical World*, vol. xl.
§ *Trans. American Inst. of Electrical Engineers*, May, 1902.
‖ "Dynamos and Alternators," by G. Kapp.

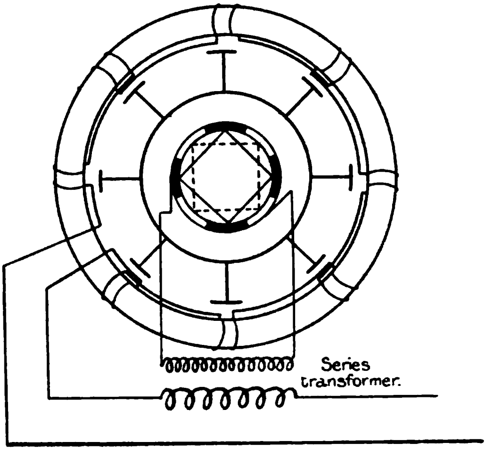


FIG. 34.

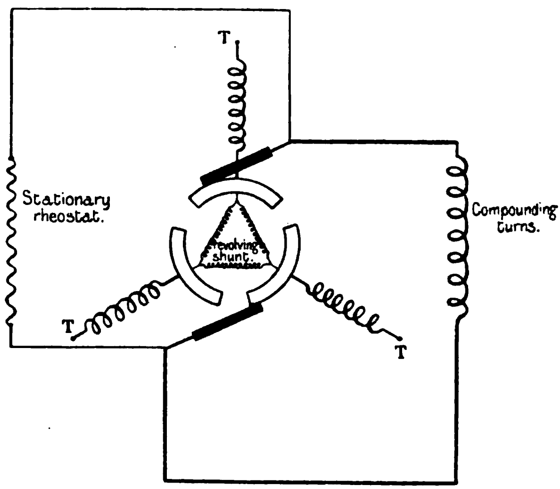


FIG. 35.—General Electric Co.'s compounded 3-phase generator.
[T T T, Terminals of armature winding.]

This may be effected by furnishing the rotating portion of the machine with a commutator having as many segments as there are field poles, and leading the main current in a rectified form round the series winding by means of brushes suitably placed on the commutator. In order to avoid passing the whole of the armature current through the commutator and series winding it may be passed through the primary of a "current" transformer whose secondary terminals are connected to the brushes so that the voltage impressed on the compound winding varies with the external current. Such an arrangement is shown diagrammatically in Fig. 34. If the machine is of the revolving armature type the transformer would be mounted on the armature spider and connected between one end of the armature winding and the corresponding collecting ring.

A similar arrangement has also been employed by the General Electric Company of America in the case of 3-phase generators; instead of connecting together the three branches of the star winding at the neutral point, they are joined to a 3-part commutator upon which press a pair of brushes connected to the series winding on the field magnets. For the purpose of avoiding sparking at the commutator and also to divert a part of the current from the series turns, the segments are shunted by a 3-branched resistance, and for regulating the extent of the compounding the series turns are also shunted by a rheostat external to the machine (Fig. 35).

The disadvantage of compounding an alternator by rectifying the armature current and passing it through a series winding on the field poles is that the machine is compounded to the same extent whatever the power-factor load may be; whereas, as has been seen above, the fall of terminal voltage is much greater on an inductive than on a non-inductive load, and hence a machine compounded on this principle might be designed to regulate well on loads of a certain power-factor, but would in general be under- or over-compounded on loads of another.

It is true that the amount of compounding can be diminished if the brushes are so shifted on the commutator that the compounding current is "commutated" at an instant when it is not passing through its zero value, so as to flow in the reverse direction round the series coils for a certain period in each cycle instead of being always unidirectional. Such an arrangement however is objectionable owing to the heavy sparking which occurs on commutating at the wrong instant.

In order to obviate the difficulties and to make a machine compound automatically on loads of various power-factors, an ingenious arrangement has been devised by Mr. E. W. Rice,* which has been successfully employed by the General Electric Company on some of their revolving field alternators.

The device, sometimes known as a "compensated exciter," utilises the effect which armature reaction produces upon the resultant field strength of the exciter.

* *Electrical World*, April 27, 1901.

The arrangement is shown diagrammatically in Fig. 36, the alternator itself being a 3-phase machine of the revolving field type.

Mounted on the same shaft as the alternator field poles is the armature of the direct current exciter, which is furnished with external stationary field magnets equal in number to the revolving field poles of the alternator. The armature of the exciter is fitted with a commutator at one end and three slip rings at the other in the manner of a 3-phase converter, and is shunt excited from the direct current or commutator side. The main current from the alternator—or rather a current proportional to this and of the same phase, derived from a 3-phase current transformer in the main circuit—is led into the armature through the

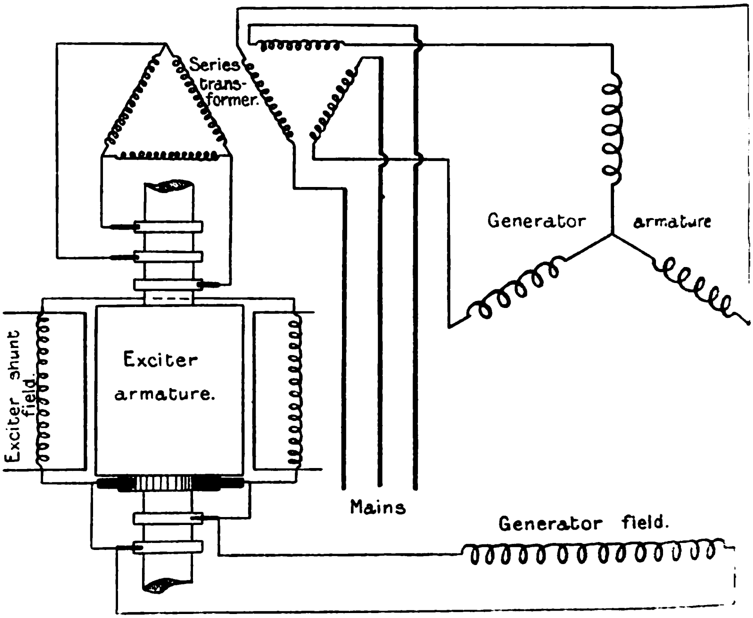


FIG. 36.—Rice-Reist "compensated exciter." Diagram of connections.

three slip rings, and in consequence of the synchronous rotation of the exciter armature produces a magnetic effect which is stationary in space and therefore in respect to the fixed field poles of the exciter. The effect of this reaction depends upon the magnitude and phase of the current producing it, as was pointed out above in connection with armature reaction in synchronous motors—strengthening the field if lagging, weakening it if leading and merely producing a cross-magnetising effect if in phase with the nominal induced E.M.F., and hence if the alternator field be excited from the brushes of the exciter (through a pair of slip rings) its excitation will be automatically increased as the load in the main circuit increases and also as the main load becomes more inductive; conditions which have been seen to be essential for maintaining a constant bus-bar voltage.

The extent of the "compounding action depends upon the relative position of the exciter armature flux and the exciter field poles, and in order that this may be adjusted if desired, Mr. H. G. Reist* has designed a machine in which the exciter poles may be turned through an angle in space, thus allowing the amount of compounding on any given power-factor of load to be adjusted.

Machines constructed on these lines appear to operate very satisfactorily, and can supply sudden inductive loads in a manner which would be impossible in the case of an alternator dependent on the ordinary hand regulation.

Asynchronous Machines.

We have hitherto considered some of the chief properties of *synchronous* generators, that is to say, machines whose frequency is exactly synchronous with the speed of rotation at all loads, and given under all conditions by the product of revolutions per second and number of pairs of poles, *i.e.*,

$$n = \gamma\, p,$$

or in the case of inductor generators by the product of revolutions and number of inductor lugs.

There is an important type of generator which has recently received considerable attention, and which on account of many valuable properties may be expected to play an important part in alternating current practice in the future. This type is the *asynchronous*, or as sometimes called the *Induction* Generator, which differs fundamentally from the synchronous machine in having a frequency not perfectly synchronous with the speed of rotation, but being (at constant speed) to a certain extent dependent on the load.

In its simplest form the asynchronous generator is an ordinary induction motor with the rotor mechanically driven above synchronous speed. Under these conditions it is well known that the machine acts as a generator and can supply electrical energy from the stator terminals.

The general equations for the induction machine giving the relation between torque, power and speed are of the form—

$$T = \frac{E_1^2 R_2 S}{R_2^2 + S^2 x_2^2} \quad \text{and} \quad P = \frac{E_1^2 R_2 S (1 - S)}{R_2^2 + S^2 x_2^2}$$

where S is the "slip" expressed as a fraction of synchronous speed.

This equation gives a relation between torque and speed as shown in Fig. 37.

Between $S = 1{\cdot}0$ and $S = O$, that is, between standstill and synchronism, the machine acts as the ordinary induction motor, absorbing electrical power and acting as a motor by furnishing a torque in the direction of rotation. The part of the curve with S greater than unity corresponds to the condition when the rotor is driven backwards, and

* *Western Electrician*, Nov. 25, 1899.

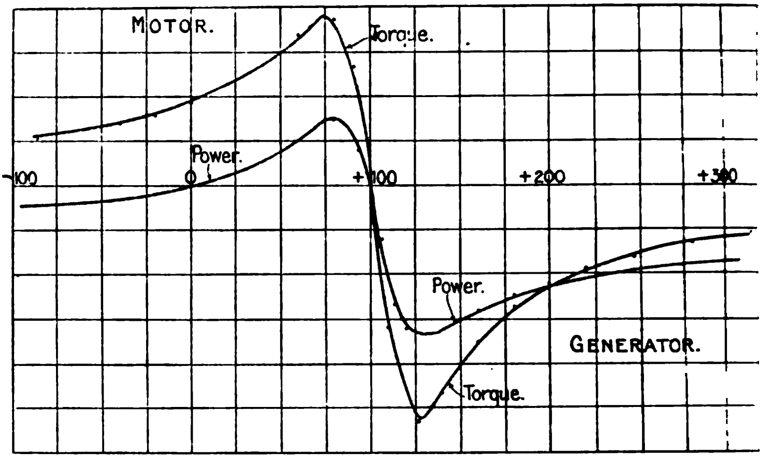


FIG. 37.—Curves of torque and speed, and power and speed in asynchronous machine.

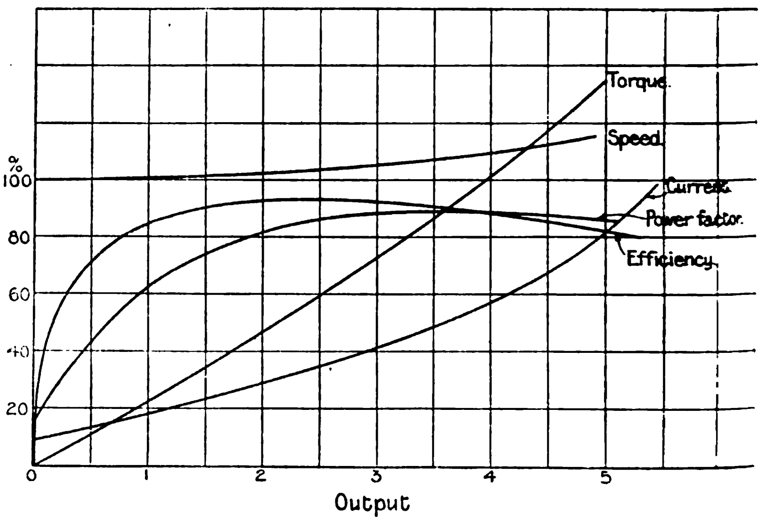


FIG. 38.—Properties of asynchronous generator.

throughout this range the sign of P is changed (*i.e.*, mechanical power is absorbed) whereas the direction of the torque is unaltered and therefore acts against the direction of rotation, so that the machine acts as a brake and itself consumes the electrical power developed.

Considering, however, the part of the curve for S having negative values, *i.e.*, rotation *above* synchronism, the signs of both T and P are changed and the machine exerts a powerful resisting torque and furnishes electrical power to the lines, and under these conditions we have the simplest form of induction or asynchronous generator.

As in the case of the asynchronous motor the region of the curves with a greater slip than that corresponding to maximum torque represents a condition of instability—*i.e.*, the torque diminishes with an increase of slip—so that within the range of working conditions the properties of the machine are best studied as functions of the output rather than of the slip (Fig. 38).

Such a machine has properties altogether different from the ordinary synchronous generator. In the first place, to generate at constant frequency, the speed must increase slightly with the load just as in the case of the induction motor the speed decreases with the load, and conversely if driven at constant speed, the frequency will fall slightly with increased load owing to the necessity of a larger "slip" (which of course is negative in the asynchronous generator).

Further, the asynchronous machine has a definite power-factor for every load, and unless the power-factor of the external circuit is adjusted to this value, the induction generator cannot operate. Bearing in mind that in the case of the induction *motor* the current must lag behind the terminal P.D., and therefore lead in respect to the (counter) E.M.F. it will be seen that the induction generator can only operate on a circuit which takes leading current, and whose power-factor varies with the load to the exact extent required by the generator. If the value of the power-factor of the external circuit be too high (so that the leading current is insufficient for the generator at that load) the machine will not excite and cannot operate, whereas if the power-factor of the external circuit be lower than that required by the machine it will excite itself and raise its voltage until by magnetic saturation (and therefore decreased permeability) the exciting current required is equal to the amount of wattless leading current in the external current.

The requisite conditions could not be realised in practice, and it is therefore necessary to have a synchronous machine connected to the stator terminals which can supply the necessary leading current to the induction generator, and secure the necessary stability of operation. The "exciter" may be a synchronous generator, in which case the current it supplies will be lagging with respect to its own E.M.F., or a synchronous motor running lightly may be employed, in which case the induction generator E.M.F. will rise until it is sufficiently below the counter E.M.F. of the synchronous motor to enable the latter to take the requisite leading current.

If the external circuit be inductive the voltage of the generator will fall until the synchronous motor takes more leading current, so that the conditions of total power-factor required by the induction generator

are satisfied; similarly the voltage of the system may be maintained constant by regulating the excitation and therefore the E.M.F. of the synchronous machine.

If the load is non-inductive the amount of leading current required will be less than in the case of an inductive load, to give the same total power-factor for the generator to operate on. Similarly if a load taking a leading current can be secured, the amount of current passing to the synchronous machine will be further reduced, until when the power-factor of the load becomes exactly that required by the generator at that output, the synchronous machine could be dispensed with, except in so far as it is required to secure regulation of voltage and stability of operation.

It would be out of place in the present instance to go into the mathematical theory of the asynchronous generator, but a diagram showing the relation of the various quantities concerned will make the operation of the machine more clearly understood. It has been urged that the operation of asynchronous machines cannot be represented by vector diagrams since the frequency of the rotor currents and E.M.F.'s is not the same as that of the stator or primary current, except at standstill; this objection, however, is not valid because in their reaction upon the stator the rotor currents are of primary frequency whatever be the speed of rotation, since the sum of the "slip" frequency and actual speed of the rotor conductors is always equal to the primary frequency. It must be borne in mind, however, that the *relative* speed of the rotor conductors and magnetic flux determines the E.M.F. induced in the rotor, and also that the reactance of the rotor at any speed is its reactance at standstill multiplied by the (percentage) slip at that speed.

Taking a vector O F (Fig. 39) to represent the flux common to both stator and rotor circuits, in quadrature and lagging behind this is the E.M.F. E_1 induced in the stator, and E_2 (proportional to the slip and therefore of negative sign) the E.M.F. induced in the rotor winding.

The rotor current is given by the vector O I_2 lagging behind O E_2 by the angle $\tan^{-1}\frac{p L_2}{R_2}$ where $p L_2$ is the leakage reactance of the rotor winding at the speed considered. In phase with O I_2 is the M.M.F. corresponding to it, and may therefore be represented by O M_2 (to a suitable scale of ampere-turns). The mutual flux O F is produced by the combined effect of rotor and stator ampere-turns, and therefore for the generator to operate it is clear that the stator current must have some such phase relation as O I_1, which is ahead of O E_1 in phase. The terminal voltage O V_1 is obtained by subtracting from O E_1, the vector of E.M.F. consumed by the stator impedance O Z, which is made up of its two components O R_1, the resistance drop in phase with O I, and the E.M.F. consumed by stator leakage reactance (of full frequency) O X_1 in quadrature ahead of O I_1.

The angle V_1 O I_1 then represents the phase difference which must exist between stator current and terminal voltage, and hence if the load is such as to give a phase difference of less than this angle, it is

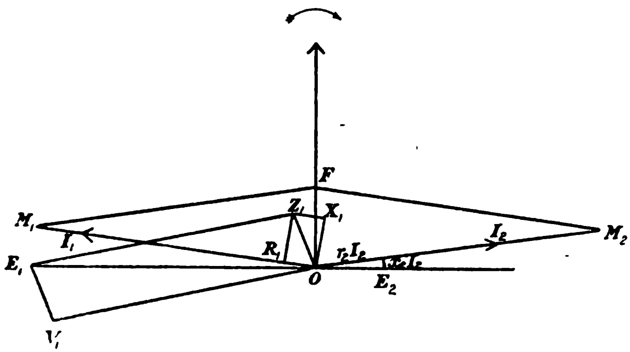


FIG 39.—Vector diagram of simple asynchronous generator.

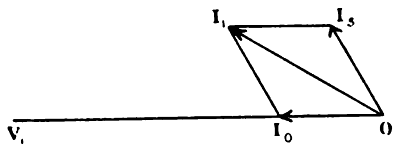


FIG. 40.

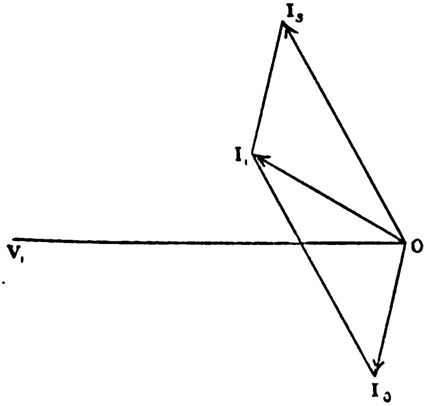


FIG. 41.

necessary to employ, in addition, some apparatus which can furnish the requisite contribution of leading current which will combine with the external load current to give, as the vector sum, O I the stator current. This additional source, as explained above, may be a synchronous generator or a synchronous motor connected to the stator terminals. Static condensers have been tried, to effect the same object; but as their power-factor is independent of the impressed voltage, such an arrangement is unstable and affords no means of voltage regulation.

The necessity of employing a synchronous machine in conjunction with an asynchronous generator is, in fact, a sufficient disadvantage to prevent the commercial adoption of this form of generator; not because there is any inherent objection to such a combination in itself, but because the size of the synchronous machine (which may be looked upon as the "exciter" for the induction generator) may have to be considerable in comparison with that of the generator itself, although contributing no power to the external load, and moreover, the synchronous machine itself requires the usual direct current machine and accompanying plant for its own excitation. It is easy to see that even on a non-inductive external load, and more especially on an inductive one that the magnitude of the leading current furnished by the synchronous exciter may be great in comparison with the external current; thus, considering the stator current of the induction generator and the terminal P.D. to be represented by the vectors $O\,I_1$ and $O\,V_1$ (Fig. 40) as before, then if the external load is non-inductive, the vector of external current $O\,I_0$ will be along $O\,V_1$, and the current flowing in the synchronous machine will be given by the vector difference of these, *i.e.*, $O\,I_s$. (Cos $V_1 O\,I_s$ is the power-factor of the synchronous machine, and therefore $V_1 O\,I_s$ can never exceed $\frac{\pi}{2}$.)

If the external circuit is inductive the conditions are even more unfavourable, and are represented in Fig. 41.

In fact, at light loads, when the power-factor (cos $V_1 O\,I_1$) of the induction generator would be small, the current in the synchronous exciter might considerably exceed that of the external load.

Figs. 42–45 are some oscillograms showing clearly these properties of the asynchronous generator.

Fig. 42 shows the conditions when there is no external load, and shows the almost wattless leading current taken by the 3-phase synchronous motor (running light and acting as the "exciter"). On putting on a small non-inductive load on the external circuit the total current supplied by the generator takes the form shown in Fig. 43, increasing in magnitude and coming more nearly in phase with the P.D. On further increasing the non-inductive load the total current from the generator becomes still more nearly in phase with the P.D. (Fig. 44) owing to the increase of power-factor of the induction machine when loaded; but the generator still has to supply a leading current to its "exciter" similar to that shown in Fig. 42, only increasing also in magnitude.

If we subtract this leading current from the total current coming

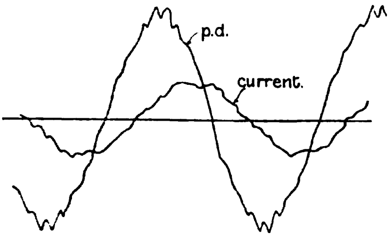


FIG. 42.

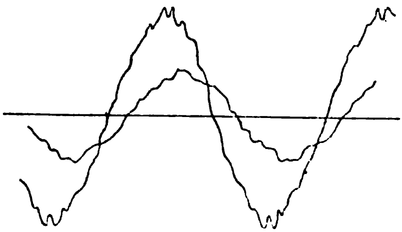


FIG. 43.

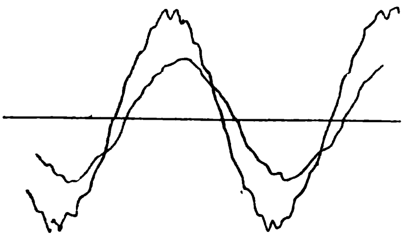


FIG. 44.

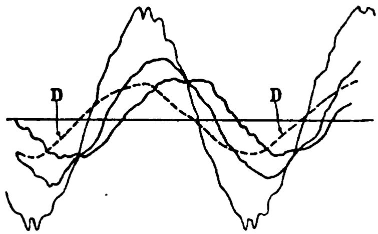


FIG. 45.

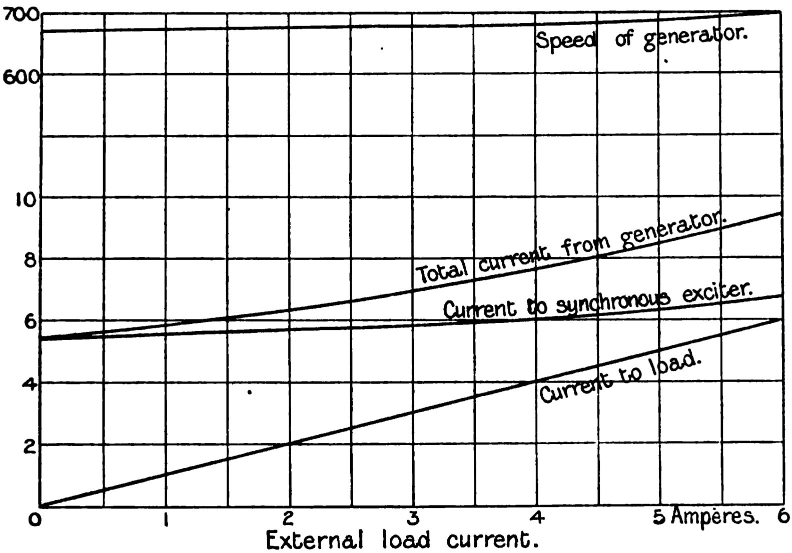


FIG. 46.-- Curves from experiment. Asynchronous generator.

from the generator we get the current wave (curve D) in Fig. 45, which is the current in the external circuit and is practically in phase with the P.D.

The curves of Fig. 46 show how the total current in the generator, and that necessary to be supplied to the exciter, vary with the external load current; also the increase of speed necessary to maintain the frequency constant—the frequency is best determined by measuring the speed of the synchronous machine. A constant terminal voltage was maintained by slightly increasing the continuous current of excitation of the synchronous machine.

These curves show very clearly the great disadvantage of the Induction Generator, namely, the relatively large current in the synchronous exciter compared with that contributed to the load. That in the case of a highly inductive load this property is still further magnified is shown by Figs. 47–49, which show the current waves under these conditions. Fig. 47 is the total current from the generator, Fig. 48 the current taken by the synchronous machine, and, by subtraction, curve D in Fig. 49 gives the current in the highly inductive load.

Although a load of almost zero power-factor would never occur in practice, these curves are interesting as showing how the "exciting" current can considerably exceed the load current when the latter is inductive. (External load current, total generator current, and synchronous exciter currents being in this case 10·1, 6·0, and 14·5 amperes respectively.) The explanation of this has been given above in the vector diagrams of operation.

In spite of the disadvantage possessed by the simple asynchronous generator in being unable to supply the wattless component of current to an inductive load, such machines possess the very valuable property of being free from all troubles in connection with *hunting* when running in parallel. In the first place, they require no exact synchronising, and may in fact be switched into circuit when running considerably below normal speed; in this case the machine will merely take current from the bus-bars and run as an ordinary asynchronous motor, and may be gradually speeded up until taking the desired share of the load. Exact governing of the prime movers is no longer of importance in the case of this class of generator, as the amount of load furnished by the machine depends simply upon its excess of speed above synchronism, and therefore is, to a certain extent, a self-governing arrangement.

Any small change in speed does not give rise to the large fluctuations and "cross currents" which occur in the case of synchronous generators running in parallel, but merely alters the proportion of the load contributed by the machine, without upsetting the stability of the combination.

This inherent property of the asynchronous generator is of the utmost value for central station work, and if the objections pointed out above, in reference to the "excitation," could be overcome, such machines would present themselves as formidable rivals to the standard synchronous generators of to-day.

SELF-EXCITED AND COMPOUNDED ASYNCHRONOUS GENERATORS.

The problem of devising a generator which can operate satisfactorily without requiring a large synchronous machine in parallel, and which at the same time retains the value properties of the simple asynchronous generator in the matter of parallel running, has as a matter of fact been solved, and such machines have recently been constructed in large sizes.

The subject of self-excited and compounded alternators has indeed been so largely developed in recent years, and so many devices have been brought out, that it is not proposed in the present paper to follow out the subject in all its branches, but only to examine those principles which give promise of adoption in practice.

The principles employed are the outcome of the earlier devices of Latour, Heyland, and others for "compensating" for the wattless current taken by the ordinary induction motor. In the "compensated" induction motor developed by Heyland the power-factor is made practically equal to unity throughout the greater range of its load, and hence such a machine when run as a generator could supply a non-inductive load without the necessity of running a large synchronous machine in parallel with it.

Space will not permit a discussion at full length of the mathematical theory of the "compensated" induction machine, but the recent developments in this direction are of so great importance to the electrical engineer, that it may be as well to consider the chief points in connection with the invention.

The basis of Mr. Heyland's device is this ; the considerable wattless component of current required by the induction machine (lagging in a motor and leading in a generator) is due to the "magnetising" current supplied by the stator winding, and the reactance of this circuit, and, therefore, the tangent of the angle of phase difference is proportional to the frequency of this magnetising current. In the simple induction machine this current is of the full frequency of the supply, and hence gives rise to a power-factor which may be considerably below unity, especially if magnetic leakage is not reduced to the smallest possible amount. If, however, instead of furnishing the magnetising current from the stator windings it be introduced by a commutator into the rotor windings, it would become in that winding a current of very low frequency (always equal, in fact, to that of the slip or asynchronism), although of full frequency in respect to its reaction upon the stator-currents, and hence would only require a small impressed E.M.F. to maintain it, and would not cause the objectionable decrease in the power-factor of the machine. For simplicity let us consider an induction machine without resistance or magnetic leakage. The vector diagram of Fig. 39 becomes that shown in Fig. 50, where O F is the flux, and $O\,I_1$, $O\,I_2$, $O\,E_1$, $O\,E_2$ the stator and rotor currents and E.M.F.'s respectively.

The magnetic flux is due to the combined action of the stator and rotor ampere-turns, so that O F is the vector sum of $O\,I_1$, and $O\,I_2$.

In order that the power-factor of the machine may be unity, the

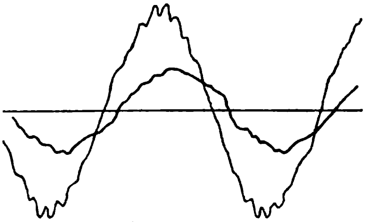


FIG. 47.

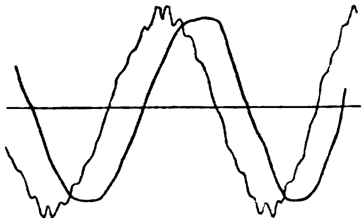


FIG. 48.

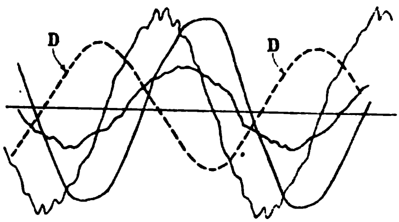


FIG. 49.

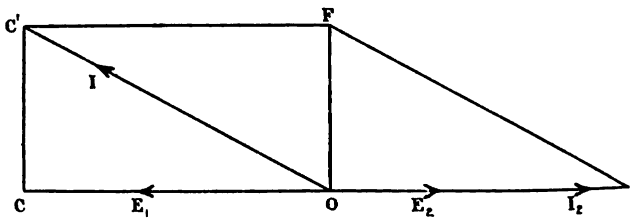


FIG. 50.

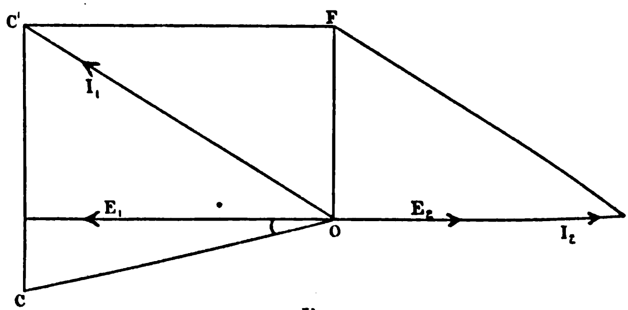


FIG. 51.

vector O I_1 must coincide in phase with O E, and, therefore, to maintain the flux O F unaltered, the current introduced into the rotor must be that corresponding to the vector C C_1. Now the magnitude of this extra current introduced into the rotor depends upon the E.M.F. applied to the brushes, and its phase (relative to the stator currents) depends upon the position of the brushes on the commutator, as the following consideration will show. Since this rotor current alternates with the frequency of the slip at all loads, and since the rotor winding itself rotates in space at a speed equal to the difference between synchronous frequency and the slip frequency, it is clear that the rotor winding is equivalent to a winding *fixed in space* and carrying currents of the full synchronous frequency. Further, since the brushes constitute the terminals of the rotor winding, it follows that by merely displacing the brushes through a certain angle, it is possible as it were to turn the "equivalent" stationary winding through the same angle in space; and thus to keep the flux unaltered, it must be adjusted so as to exactly replace that furnished by the stator magnetising current in the uncompensated motor.

Further, by sufficiently increasing the magnitude of the magnetising current introduced into the rotor, it becomes possible to reverse the power-factor of the stator circuit and make the stator take a leading current as a motor, or enable it to supply an inductive load as a generator (angle C O E, Fig 51).

As pointed out above, this extra current introduced into the rotor only requires a small impressed E.M.F. to drive it. This may be supplied from a small transformer, whose primary is connected across the stator terminals, or in low voltage machines may be obtained by "tapping" a small fraction of the stator winding, the necessary adjustment being made by resistances or altering the transformer ratio.

If such a compensated machine be worked as a motor its power-factor will remain practically unity at all loads, although to obtain this condition exactly the amount of compensating current should be increased slightly with the load in order to make up for the increase of magnetic leakage. Conversely as a generator it will maintain a nearly constant terminal voltage on a non-inductive load.

Compounding of Asynchronous Generators.

In order to regulate for constant voltage on inductive loads, it is necessary that the magnetising current introduced into the rotor be increased with the load. This represents the next step developed by Mr. Heyland in connection with his asynchronous machines, and may be effected by passing the stator current through the primary of a second transformer, whose secondary terminals are connected to brushes on the rotor commutator, or the entire stator current may be sent through the rotor by connecting the ends of the stator windings, which would otherwise be joined together as the "neutral point," directly to the brushes, in which case use of the current transformer would be obviated.

If it is desired to use the same set of brushes for the compounding and for the exciting current, the secondary of the transformer supplying the latter current must be mesh-connected, in order that the magnetising current thus introduced into the rotor may be a quarter of a period ahead of the stator voltage from which the primary of the transformer is supplied.

The arrangements of connections in such a compounded self-exciting asynchronous generator are of the form shown in Fig. 52.

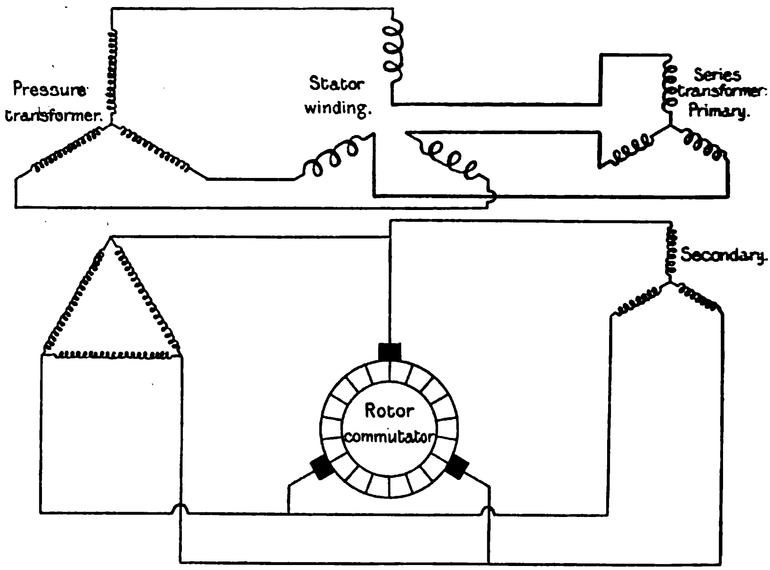


FIG. 52.—Connections of Heyland compounded, self-exciting asynchronous generator.

The extent of the compounding can be varied by altering the ratio of the current transformer or by placing suitable shunts across the brushes, and by making the necessary tests before finally adjusting these, the machine can be made to over-compound at high-loads if required.

By connecting adjacent commutator segments by low-resistance shunts, and by winding the rotor with a duplicate winding so as to obviate the self-inductive E.M.F. on opening the circuit, Mr. Heyland has been able to eliminate all troubles arising from sparking at the brushes.

THE HEYLAND COMPOUNDED SYNCHRONOUS MACHINE.

The latest development in connection with the compounding of alternators has been made by Mr. Heyland in applying the principles of his compensated asynchronous generator as outlined above, to

machines of the synchronous class.* In this case the current in the rotor will be of zero frequency, that is a direct current, and the somewhat costly rotor may be replaced by the ordinary revolving system of field poles of simple construction. The field poles are wound with a multiple winding consisting of several circuits in parallel and con-

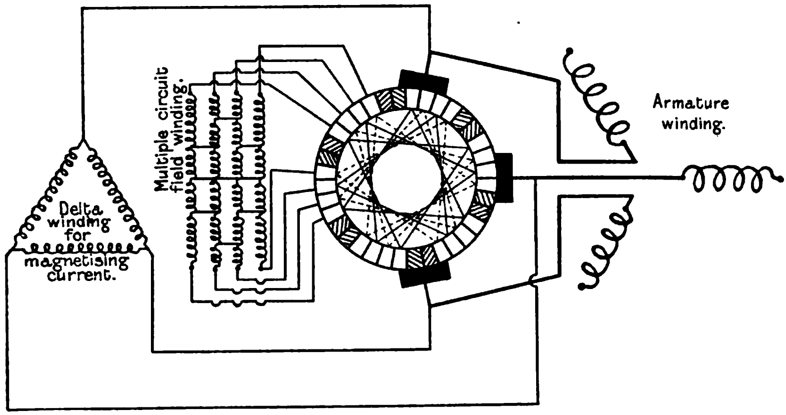


FIG. 53.—Connections of Heyland compounded synchronous generator.

nected to adjacent commutator segments so as to eliminate sparking at the brushes. The compensating or exciting current is obtained either from a step-down transformer with mesh-connected secondary, as in the asynchronous machine, or from an auxiliary mesh-connected winding on the armature itself; and the compounding current may

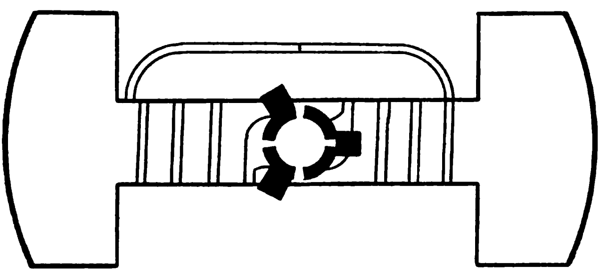


FIG. 54.—Principle of Heyland compounded synchronous generator.

also be obtained, as in the asynchronous type of machine, either from the secondary of a series current transformer, or by opening the armature winding at its middle point, and connecting to the brushes. The arrangement of connections of such a machine is shown diagram-

* Kolben, *Elektrotechn. Zeitschr.*, Oct. 8, 1903.

matically in Fig. 53. An important feature of this arrangement is that only the wattless component of the load current contributes to the compounding (this component is in phase with the compensating current from the mesh winding) so that the amount of compounding or over-compounding will increase with the inductance-factor of the load. This is exactly what is required in practice as the drop in various parts of the system increases with lagging currents.

The utilisation of only the wattless component of the current for compounding is an important feature of the Heyland synchronous generator, and is carried out on the following principle. Suppose, for simplicity, that the revolving field magnet is a 2-pole one, and wound with only 2-parallel windings connected at their middle point, and with the four ends connected to adjacent commutator segments as shown in Fig. 54.

The brushes are connected into the middle point of the star connected armature winding, or to the secondary of a current transformer; let

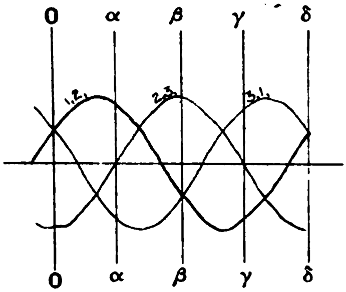


FIG. 55.

them be so placed on the commutator that they cover the segments in the manner shown in Fig. 56, I., when the wattless current between circuits 2 and 3 is passing through its zero value.

Taking the three sine curves Fig. 55 to represent the value of the wattless currents in the three circuits, it will be instructive to trace the paths of these currents throughout a complete cycle. With current 2, 3 zero (*α* Fig. 55) the currents of the other two phases will flow from brush 1 to 2, and from 1 to 3 through the magnet winding.

Considering now the paths open to the currents ¼ period later, the relative position of brushes and segments will be that of Fig. 56 II. (*cf.* *β* Fig. 55); the current in phase 2, 3 will be at its maximum and will flow round the winding from segment 2 to segment 3, while currents will also flow from 1 to 2, and 1 to 3, which latter are equal and will therefore produce no effect.

After another ¼ period, the segments and brushes will occupy position Fig. 56, III. (*cf.* *γ* Fig. 55) and conditions are exactly the reverse of position I., *i.e.*, currents flowing from 3 to 1 and 2 to 1, while current 2, 3 is zero.

Similarly, ¼ period later, the conditions are the reverse of position II., the maximum current flowing from 3 to 2 and currents from 3 to 1 and 1 to 2, the latter two cancelling each other (Fig. 56, IV. and δ Fig. 55).

In the same way it will be seen that the energy component of the current will contribute no resultant effect to the compounding, for remembering that this component is ¼ *ahead* of the wattless component, the values of the three energy currents at the instants O, α, β, γ, of Fig. 55 will occur when the relative position of the brushes and commutator

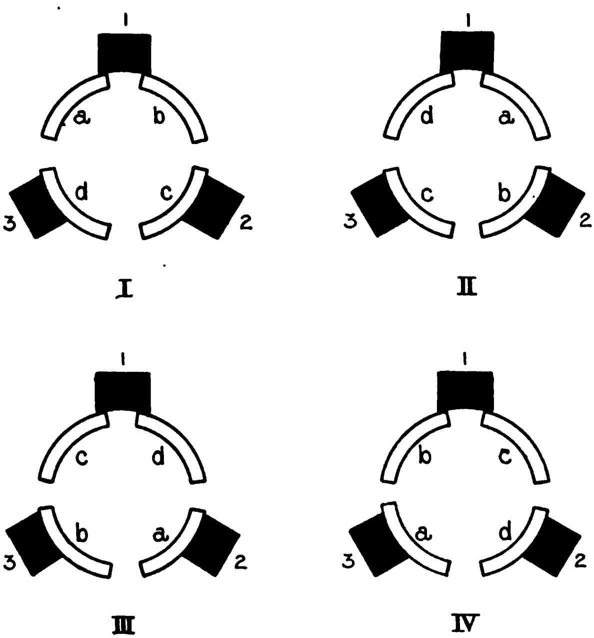


FIG. 56.

segments is that of I., II., III., and IV. in Fig. 56, respectively, *i.e.*, the resultant effect of the energy currents is zero throughout.

This property of the Heyland machine to compound to a greater extent on inductive loads is of the greatest value, as it is under these circumstances that the drop in all parts of distributing system is greatest; whereas, in the case of the ordinary uncompounded generators, as shown in the earlier part of this paper, the terminal voltage falls off more rapidly as the power-factor of the inductive load is decreased.

In his most recent machines, Mr. Heyland adopts a field winding consisting of more than two circuits, which necessitates wider brushes, or several brushes arranged slightly behind each other, so as to cover the requisite number of segments. By this arrangement and by

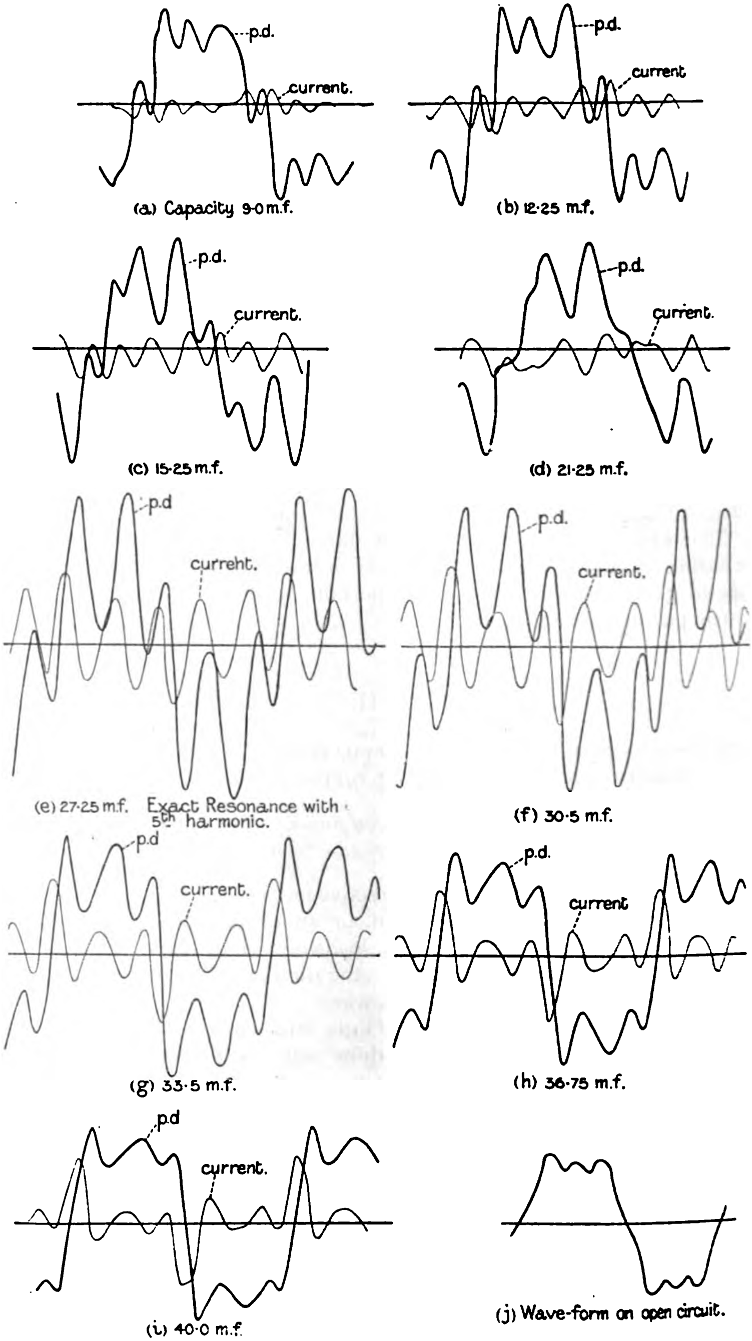

p.d.
current.
(a) Capacity 9·0 m.f.
p.d.
current
(b) 12·25 m.f.
p.d.
current.
(c) 15·25 m.f.
p.d.
current.
(d) 21·25 m.f.
p.d
curreht.
(e) 27·25 m.f. Exact Resonance with 5th harmonic.
p.d.
current.
(f) 30·5 m.f.
p.d
current.
(g) 33·5 m.f.
p.d.
current
(h) 36·75 m.f.
p.d
current.
(i) 40·0 m.f.
(j) Wave-form on open circuit.

FIG. 57.

inserting "dead" segments between the groups connected to the winding, it has been found possible to obtain sparkless running without employing the connecting strips between the segments, as was done in the earlier compounded *asynchronous* generators.

In multipolar machines, similar commutator segments are joined by connectors in the manner of continuous current machines.

The arrangement of circuits in such a 6-pole machine is shown diagrammatically in Fig. 53.

Tests on these machines bear out the valuable qualities in their regulation and appear to justify the prediction that they have a wide field of utility before them.

From a commercial point of view, a comparison of the relative cost of production of the standard type and the compounded type of generator is of course of great moment. In making this comparison, it must be borne in mind that the cost of the exciter and exciter-sets has to be added to that of the generator, whereas, in the self-excited compounded type, it is, as it were, self-contained in the machine, and moreover this type would materially reduce the cost of switchboard fittings and connections.

Time will show to what extent the standard practice of to-day will be modified in this respect, but evidence seems to show that this recent type of generator will hold an important place in the alternating current practice of the future.

PART II.

SOME OSCILLOGRAMS SHOWING THE BEHAVIOUR OF ALTERNATORS AND SYNCHRONOUS MOTORS UNDER DIFFERENT CONDITIONS.

(*a*) *An Electrical Resonance phenomenon and its effect on the wave form of an alternator.*

It occurred to the writer that the effective inductance of an alternator armature might be measured without an abnormal condition of the excitation, by loading it into condenser loads of various magnitudes and obtaining a resonance effect either with the fundamental, or, if possible, with a higher harmonic of the E.M.F. wave.

The experiments resulted in a very interesting series of oscillograms which are shown in Fig. 57. The machine used was the Fynn Inductor Alternator, whose open circuit E.M.F. wave contains pronounced triple and quintuple harmonics (Fig. 57 *j* and Fig. 1).

By gradually increasing the capacity of the load by adding condensers in parallel, the change of wave from across the terminals was very remarkable, and is shown in Fig. 57, *a to e*, until, when a capacity of 27·25 microfarads was reached, exact resonance with the harmonic of quintuple frequency took place, the wave-forms taking the form of (*e* Fig. 57). The current at this stage is seen to be almost a simple sine wave of five times the fundamental frequency, and, as would be expected, each of these higher pulsations is in quadrature with the corresponding peak and hollow of the P.D. wave.

On further increasing the capacity, the resonance was quickly destroyed, the wave-forms becoming again more normal as shown by Fig. 57 *f* to *i*.

The rise of voltage at the condition of complete resonance with the 5th harmonic was from 200 to 286, though this would partly be due to the fact that the machine was then giving a wattless leading current of three-quarters of its full load current, which, as previously shown, gives in itself a rise of terminal pressure.

To calculate the effective inductance of the armature, we have at resonance

$$p\,L = \frac{1}{p\,K}$$

The frequency of the fundamental wave was in this case 57 ∿ per sec., and hence at quintuple frequency

$$\begin{aligned} p_5\,L &= \frac{1}{2\,\pi \times 285 \times 27{\cdot}25 \times 10^{-6}} \text{ ohms} \\ &= 20{\cdot}5 \end{aligned}$$

i.e., a Reactance of 4·1 ohms at the fundamental frequency.

This shows a very fair agreement with the value 4·38 of the Synchronous Reactance, found from the open- and short-circuit characteristics of the machine at that frequency.

It is clear that, owing to the introduction of resonance with the higher harmonics of the E.M.F. wave, the theoretical regulation curve of an alternator on a capacity load of given power-factor—such as that shown in Fig. 10—cannot possibly be obtained in practice unless the E.M.F. wave be a simple sine wave. In practice, however, capacity loads of any great magnitude are seldom met with, so that the point is chiefly of theoretical interest.

(*b*) *Some Oscillograms illustrating the Modification of Wave-forms under different Conditions.*

Fig. 58 shows the open-circuit E.M.F. wave-form of the Fuller-Wenström Single-phase Alternator, showing very distinctly the ripples of high frequency due to the slots on the armature.

These ripples can be greatly intensified by resonance as is exemplified by Fig. 59, which represents the P.D. wave-form when working on a condenser load of 27·25 microfarads capacity. The current is then a wattless current of fifteen times the fundamental frequency.

The lack of exact symmetry about a vertical axis is further increased.

Fig. 60 shows a slight alteration in the E.M.F. wave-form on the *unloaded* phase of the Fynn 2-phaser when a capacity current is taken from the other phase. The capacity in this case was such as to give nearly exact resonance with the quintuple harmonic as described above.

As a further instance of the effect of different loads on the wave-forms of a machine are shown Figs. 61 to 64, which are oscillograms taken from the E. C. C. 3-phaser; with star-connected armature.

Fig. 61 is the E.M.F. wave on open circuit, and verifies the fact that in a star-connected 3-phase armature the E.M.F. wave from between any pair of terminals can contain no harmonic of triple frequency since it is the difference of two identical waves differing in phase by $\frac{2\pi}{3}$. It will be noticed that except for the ripples (of 17th frequency) this wave is very nearly sinusoidal.

When working on a balanced inductive load of small magnitude a

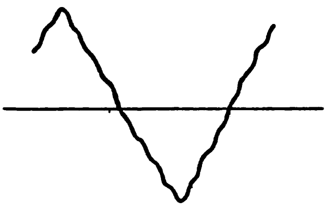


FIG. 58.

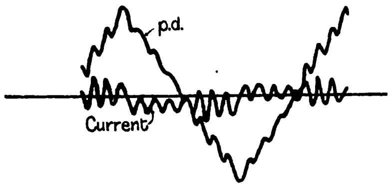


FIG. 59.

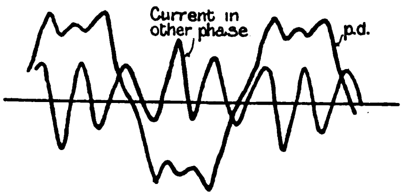


FIG. 60.

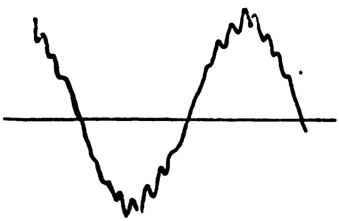


FIG. 61.

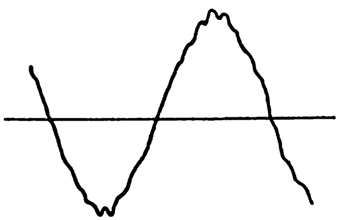


FIG. 62.

slight modification in the ripples takes place, as in Fig. 62, which shows the P.D. when running an unloaded 3-phase induction motor.

As an instance of unbalanced loads are shown Figs. 63 and 64. The former being the P.D. on the unloaded phase when running the same induction motor unloaded on a single-phase, and Fig. 64 showing the E.M.F. wave on one-phase when a second-phase is short-circuited—this short-circuit current wave is also shown in its correct phase relation. The alteration in the E.M.F. wave under these unsymmetrical conditions is very marked.

The wave-forms obtained from the terminals of the armature

winding of an alternator represent in all cases the combined effect of the E.M.F.'s induced in two coils (or in a multipolar machine, in two sets of coils) wound in opposite directions, the E.M.F. at any instant being proportional to the rate at which the flux through the coil is changing, and hence since the two oppositely wound coils are connected in series the E.M.F. wave will be symmetrical about the axis of displacement, *i.e.*, can contain only harmonics of triple, quintuple, etc., frequency.

If, however, we consider the E.M.F. induced in a single armature conductor in one side of any particular armature coil as it rotates; it is clear that the wave-form of this E.M.F. is not necessarily symmetrical in all types of machine, and will, moreover, afford an insight into the conditions of the magnetic flux in the air-gap or the surface of the armature during the complete cycle.

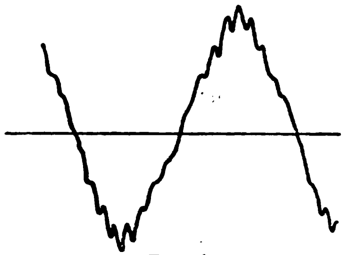


FIG. 63.

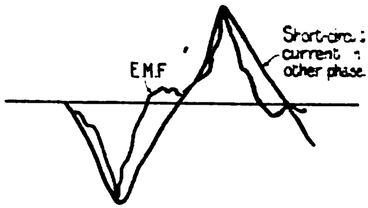


FIG. 64.

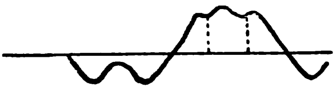


FIG. 65.

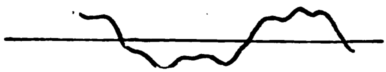


FIG. 66.

In a machine of this revolving field magnet, or revolving armature type, each half-wave of E.M.F. induced in a single armature conductor will be identical if the consecutive field poles are identical in form but in a machine of the inductor type where each conductor passes successively from a region of maximum to that of minimum flux—the flux itself never reversing in direction—the E.M.F. in each conductor will not be symmetrical.

As an instance of this is shown the wave of E.M.F. induced in a conductor threaded through a single armature slot in the Fynn Inductor alternator, and connected to an oscillograph (Fig. 65).

It will be noticed that the E.M.F. is actually reversed in direction, and undergoes an alternation of an unsymmetrical form. Now, if the conductor were simply passing through a field, never changing its polarity, but merely varying in intensity from a maximum to a minimum, the E.M.F. induced in the conductor would not alternate in sign, and the wave-form would be a pulsation lying wholly on one side of the zero line. Hence the reversal of E.M.F. shown in the accompanying oscillogram must be accounted for by the bands of flux

periodically springing back across the slot to enter the armature tooth which at that moment would be coming under the inductor lug.

The machine in question had a two-phase winding, giving altogether four slots per pole, and it will be noticed that there are four depressions in each complete wave in the oscillogram.

On taking a condenser current from the phase other than that through which the search-wire was threaded, the wave undergoes a modification as shown in Fig. 66; due to the change of actually existing flux distribution by armature reaction, and partly due to the presence of leakage flux from the loaded phase.

The loaded phase was at the time under the conditions shown in *e*, Fig. 57, giving a current of five times the fundamental frequency due to exact resonance with the 5th harmonic in the E.M.F. wave, as described above.

Some Wave-form Effects in Synchronous Motors.

The assumption that the E.M.F. wave-forms of alternators are sinusoidal, or even approximately so, is often too far from the truth to be made when considering many of the secondary and more abstruse phenomena which may occur in alternating-current circuits.

A case which is met with in practice is that of a synchronous motor or converter having a different open-circuit E.M.F. wave-form from that of the generator driving it.

In such a case the wave-form of current taken by the synchronous motor may assume very remarkable forms, and may undergo very striking modifications when the excitation or the load of the motor is varied.

The theory of the "ideal" synchronous motor has long been understood, and represents a very interesting and elegant mathematical investigation. Such an "ideal" is the motor having counter E.M.F. of simple sine-wave form, and an armature of constant self-induction, working with a sine-wave of P.D. impressed across its terminals. The behaviour of such a motor is common property of all text-books. The current is also sinusoidal and determined in phase by the extent of field excitation and load, lagging behind the terminal volts when "under-excited," and shifting forward in phase with increase of excitation until, when the counter E.M.F. is sufficiently in excess of the terminal P.D., the current becomes a leading one, and the motor is said to be "over-excited." The armature current must of necessity undergo corresponding changes of magnitude (under any given load) owing to the successive changes of power-factor caused by the displacement of phase.

By plotting curves connecting the armature current and the field current (or more correctly the counter E.M.F., which of course is not proportional to the field current) the well-known "V" curves of the synchronous motor are obtained, from which, indeed, many important properties of the synchronous motor may be deduced.

A set of these V curves may be obtained by experiment from any synchronous motor, and so long as only R.M.S. values of the E.M.F.

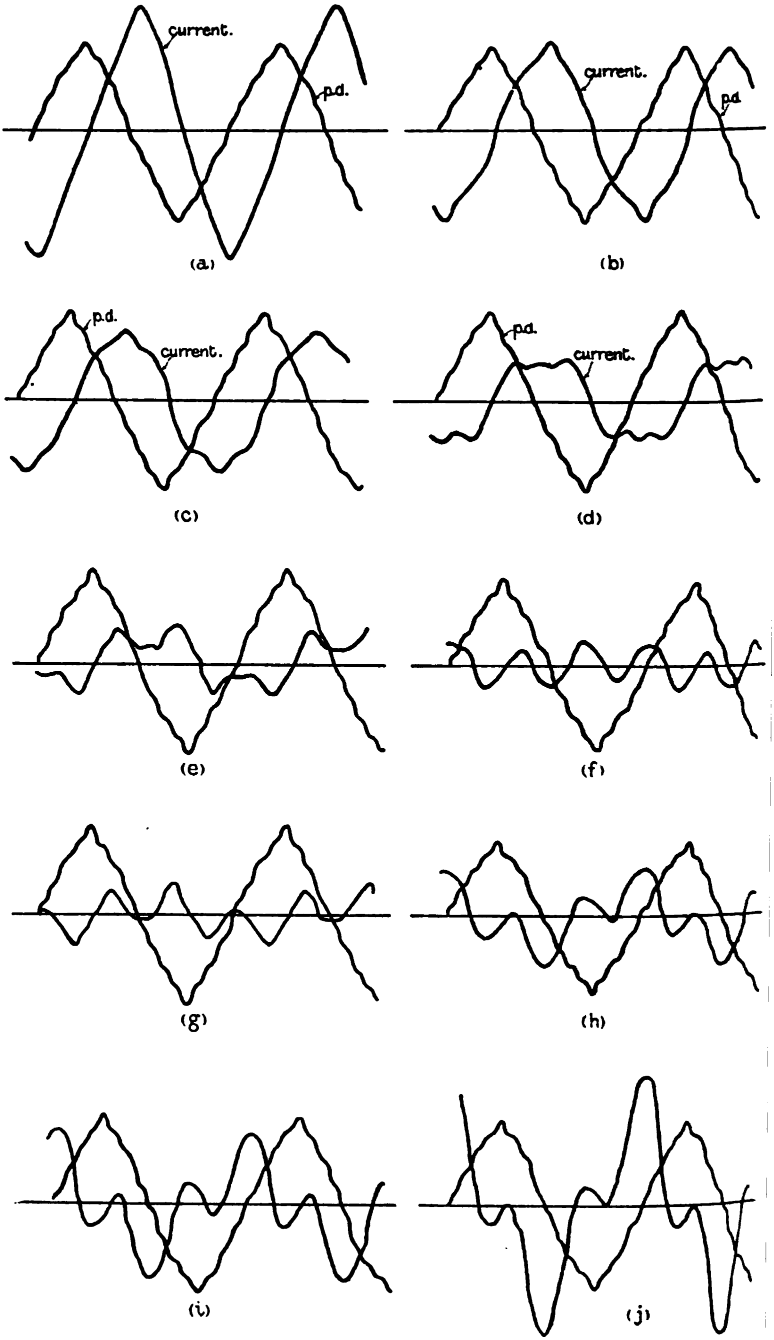


Fig. 67.

and armature current are considered, the theoretical treatment appears very closely in accordance with the experimental results.

A more detailed examination of what is really taking place, however, shows some interesting effects.

The accompanying illustrations show the wave-forms of current taken by a synchronous motor whose open-circuit E.M.F. wave-form differs considerably from that of the generator driving it, Fig. 58 being that of the generator, and Fig. 2 that of the motor.

The generator was the 12½-k.w. single-phaser by Fuller-Wenström with revolving armature (machine "D" previously referred to), having four slots per pole, and giving the somewhat remarkable triangular wave-form shown.

The machine used as the synchronous motor was a smaller machine of the Fynn inductor type—in reality a 2-phaser with two slots per phase per "armature pole" (the number of inductors being naturally half that of armature coils of each phase), but with one phase entirely unused throughout the tests—of 5-k.w. output as a 2-phaser or 2½ k.w. as single-phaser (the machine "A" mentioned above).

This arrangement gives us an example of a synchronous motor driven by a generator of considerably larger capacity, and neither of the machines giving sine waves of E.M.F.

The oscillograms, Fig. 67, *a* to *j*, show the form of P.D. and the controlling current when the motor was running light under different degrees of excitation, Fig. 67 *f* being the condition when the motor excitation was such as gave rise to the minimum value of controlling current—*i.e.*, the lowest point on the "V" curve. The current in this case was practically identical in form to that obtained after synchronising but before cutting off the driving power from the motor—that is to say, the controlling current of the two machines running in parallel unloaded. It may be mentioned that the generator was driven throughout by a direct-current motor, so that no periodic fluctuations of driving torque occurred.

On throwing off the belt from the synchronous motor (thus mechanically disconnecting it from a second D.C. motor which had been used to run it up to synchronism) and gradually weakening its field excitation, the current wave undergoes the remarkable alterations shown in Figs. 67 *f* to *a*, becoming more and more lagging in phase. On gradually strengthening the excitation (thus working along the other side of the V curve) the current wave again undergoes striking changes in form and develops an increasing lead in phase (Fig. 67 *f* to *j*).

It will be noticed that the open-circuit E.M.F. wave-form of the motor is completely obliterated throughout, the wave-form of P.D. across the terminals being that of the larger machine (in this case the generator) throughout.

On interchanging the two machines and running the larger one as a synchronous motor from the small one as generator, this was still found to be the case, the E.M.F. wave-form of the smaller machine never being at all discernible; this would result from the reactive effect of the same armature current on the field systems being relatively much

more powerful in the case of the small machine than the large one; and, further, the ratio of armature turns to field coil turns being 1 to 120 in the large machine, as compared with 1 to 48 in the small machine (or 1 to 96 if we consider the field to be reacted upon by only half the armature coils in the inductor type of machine).

As an example of a synchronous motor of about the same output as the generator driving it, are shown Figs. 68 *a* to *f*.

The inductor machine described above was run as a synchronous motor driven by a generator whose open-circuit wave-form has been shown in Fig. 38.

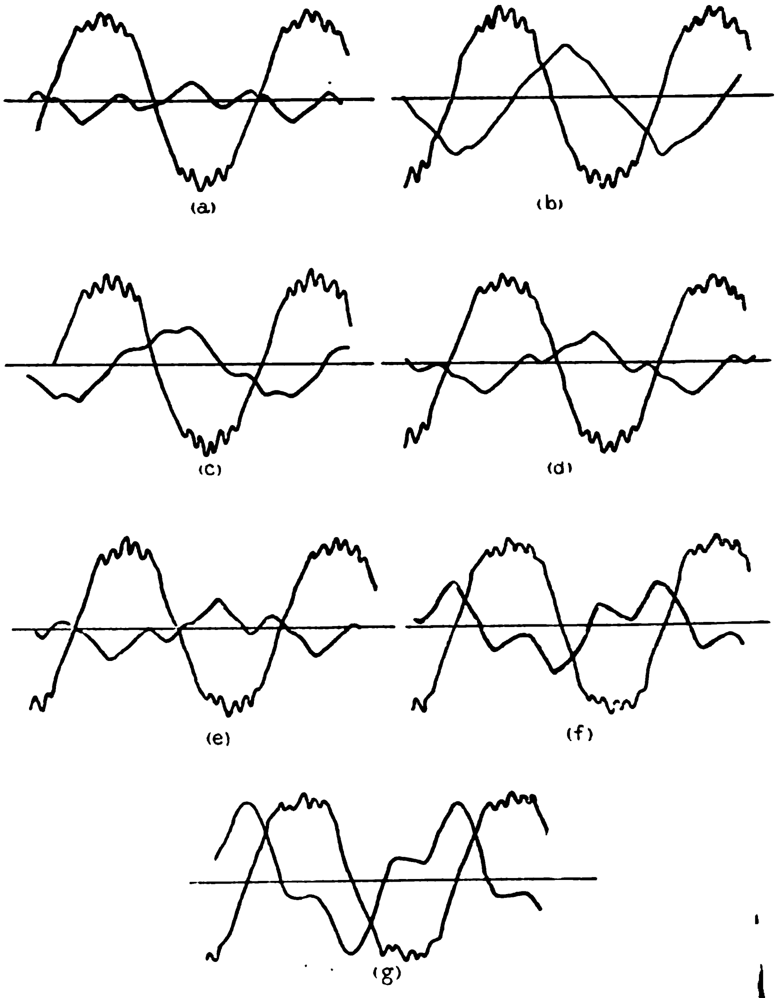


FIG. 68.

This machine (the E.C.C. Machine "C") is in reality a 3-phaser, but was only used as a single-phaser in these experiments. Since the armature was star-connected there is an absence of the harmonic of triple frequency in the E.M.F. wave, which is, in fact, nearly sinusoidal except for the high frequency "ripples" produced by the armature slots.

Fig. 68*a* shows the P.D. and current waves when the two machines are running in parallel and unloaded. The P.D. wave-form is then intermediate between those of the two machines individually, as would be expected from the fact of the machines being about of the same size and both normally excited. On gradually reducing the excitation of the synchronous motor (the inductor machine), the wave-forms undergo the modifications shown in Fig. 68, *d*, *c*, *b*, successively, the current becoming more and more lagging and completely changing its form, while the P.D. wave approaches more and more to the open circuit wave-form of the more strongly-excited machine (generator). If, instead of being reduced, the excitation of the synchronous motor be *increased* the waves in Figs. 68, *e* and *f* result; the current gaining in phase and the P.D. wave approaching more nearly the flat-topped wave of the motor E.M.F. (now the more strongly excited by the two machines).

On interchanging the machines and running the inductor machine as the generator and the other as the synchronous motor, the P.D. wave still approaches the form of the more strongly-excited machine (Fig. 69*a* with motor under-excited, and Fig. 69*b* with motor over-excited).

If, instead of running light, the motor is mechanically loaded, the wave-forms are more distorted, Fig. 70*a* showing the inductor machine as motor under-excited and Fig. 70*b* the waves with the motor loaded to the same extent, but over-excited. The current is, of course, more nearly in phase with the P.D. owing to the power component which is required under load.

Similar examples of change of wave-form may be obtained in almost endless variety by altering the load and excitation; and in order to account for the remarkable forms which the current wave may assume, it is important to consider carefully the causes which affect it.

At any instant the current will be determined by the difference between the P.D. impressed across the motor terminals and the complete counter E.M.F. induced in the motor armature, or at any instant

$$i = \frac{v - e}{r}$$

Now if the generator is considerably larger than the motor, the value of v (if the line itself is non-inductive) will practically be that given by the open-circuit wave-form of the generator. The total E.M.F. induced in the motor armature, however, is due to a variety of causes. First, there is the E.M.F. due to the motion of the conductors across the existing field. This fixed distribution, however, is not that which

exists when the machine is run on open circuit, but is modified as a whole by armature reaction, the extent of the modification and distortion depending upon the general angular relation of current wave and position of field poles in space; that is, on the general phase of the current and open circuit E.M.F. waves (these being, in general, of different forms cannot be considered to have a *definite* angle of phase difference).

There is further the E.M.F. induced in the conductors by the rise and fall of armature leakage flux or E.M.F. of true self-induction. This E.M.F. will be of a complex nature, but at any instant is

$$\frac{d\,(\mathrm{L}\,i)}{dt}$$

where L is the coefficient of leakage inductance of the armature at the instant considered. This inductance, however, is not constant, but is a function of the time (being dependent upon the relative position, in space, of armature coil, and field pole) and, to a certain extent, of the current strength itself.

Since the current itself is in general a complicated periodic function of the time, it is clear that the leakage self-inductive E.M.F. may readily undergo great modifications by altering the working conditions of the motor.

Further, any irregularities or harmonics in the current-wave are intensified in its time-rate of change, and hence, even if the inductance were constant, and not a function of the time, the self-inductive E.M.F. would be of an extremely irregular form.

In the case of a single-phase machine, the effect of armature reaction is pulsating in character, being of double the fundamental frequency, but in a polyphase machine the resultant effect is nearly constant, and hence the resultant field remains modified as a whole by the reaction of the armature currents, the extent of the modification depending on the general phase of the current-wave.

As previously pointed out in connection with armature reaction in alternating current generators, the leakage-flux combines with the mutual flux to produce a resultant flux which induces the complete E.M.F. in the armature conductors, although for the purpose of analysis it is more convenient to consider each flux as inducing its own E.M.F., and then to consider these E.M.F.'s to combine into a final resultant E.M.F.

The effect of altering the excitation of the motor is to slightly retard or accelerate the rotor until the armature current-wave has assumed its phase-relation with the field poles corresponding to the changed excitation. This not only alters the field distortion and therefore the wave-form of the corresponding part of the counter E.M.F., but also directly alters the nature of the E.M.F. of leakage self-induction, since the variations in the coefficient of inductance will occur while the time-rate of change in the current is different owing to the general displacement of the current-wave.

A similar effect is produced by an alteration of the load on the

motor; an increase of load momentarily retarding the armature until it assumes in space such a phase as gives rise to the necessary torque under the new load. If the maximum limit of this displacement is exceeded, the machine of course falls out of step from excessive overload.

Note on Parallel Running of Synchronous Machines.

The question of "hunting" of synchronous machines when electrically connected, resolves itself into a consideration of oscillation about a state of stability and steady motion; and, provided that definite data can be laid down concerning the forces which determine the nature of the "free" oscillations of the rotor, and also those which give rise to the "forced" oscillations, the question is one which is capable of exact mathematical analysis.

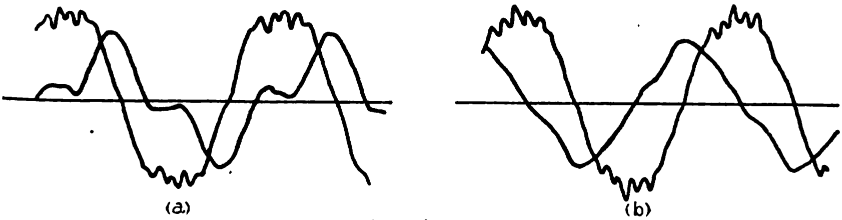


Fig. 69.

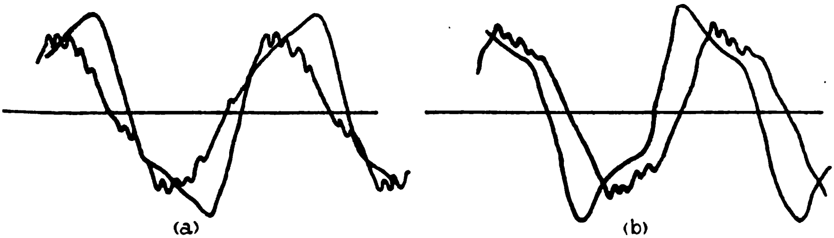


Fig. 70.

The subject, indeed, has called forth more mathematical expositions than perhaps any question in connection with alternating-current working. Admirable as these investigations are, more careful study of the conditions existing in actual cases seems to show that a rigid solution of the question is to all intents impracticable for the reason that the data assumed are not sufficiently general to cover all the conditions of the case in question.

Variations in the angular velocity of one machine form a primary source of hunting and unsatisfactory parallel running, in which case the fault rests fundamentally with the prime mover, and may generally be remedied to a certain extent by adjustment of flywheel capacity so that the moment of inertia of the rotating masses is not such as may give rise to partial resonance.

The effects shown above in the oscillograms, Figs. 67 and 68, suggest that in the case of machines of different wave-form, conditions may exist which would give rise to unsteady parallel running without any irregularity on the part of the prime mover; namely, the flow of *power* between the machines, which in the case of such irregular current wave-forms may undergo rapid alternations in direction. The wave of power, in fact, being the product of the waves of P.D. and current, reverses in direction whenever either of these factors passes through zero separately, and will therefore have a number of reversals per second equai to the sum of the reversals in the P.D. and current-waves. Now a reversal in the direction of the transmitted power—*i.e.*, a change from motor to generator action in either machine, will be accompanied by a reversal of mechanical stress in the machines, which, if of suitable frequency, might set up hunting.

It will be seen from the above oscillograms that a change in the excitation of such dissimilar machines may so change the form of the current-wave that the number of alternations in the power-wave may be greatly altered.

This view is confirmed by the fact that it was found impossible to run machine "C" previously referred to (open-circuit wave form shown in Fig. 61) as an unloaded synchronous motor from machine "D" (Fig. 58) as generator, except with the excitation adjusted within narrow limits. Otherwise—although the generator was driven by a direct-current motor and therefore free from periodic fluctuations of the prime mover—hunting developed spontaneously and rapidly increased in violence, until the machines finally dropped out of step.

By inserting a choking coil, however, between the machines, or by putting a load on the synchronous motor, the hunting could at once be got rid of, owing to the fact that the current-wave was made smooth in form, and hence the rapid fluctuations in the direction of the transmitted power were considerably decreased.

Compounded alternators work well in parallel, but it appears desirable to employ "equalising connectors," as in the case of compounded continuous-current generators, or else to only employ one compounded machine to run in parallel with the rest of the plant, which may be simply self-exciting alternators.

It is, in fact, in accordance with common experience that unsteady parallel running may often be improved by an alteration in the excitation of one machine; though the effect is usually attributed to the alteration produced in the time-period of the natural oscillations of the rotor concerned.

BIBLIOGRAPHY.

Besides those previously given, the following references will be found of value.

ARMATURE REACTION AND REGULATION OF ALTERNATORS.

Arnold. "Electrotechnische Zeitschrift," March 20, 1902.
Blondel. " " June 6, 1901.
Behrend. " " November 30, 1899.

Behrend. American Inst. E.E., June and July, 1903.
Fischer-Hinnen. "Ztschr. Electrotechn.," Wien, January 19 and 26, 1902.
Fischer-Hinnen. "E.T.Z.," December 26, 1901.
Giles. "Eclairage Elec.," April, 1901.
Kesselring. "E.T.Z.," October 2, 1902.
McAllister. "American Electrician," August, 1901.
Niethammer. "E.T.Z.," March 21, 1901; June 6, 1901.
" "Electrician," April 15, 1904.
Poitier. "Comptes rendus," October 23, 1899.
Rey. "Industrie Electr.," May, 1901.

SELF-EXCITING AND COMPOUNDING ALTERNATORS.

Adams. American Inst. E.E. June and July, 1903.
Baum. " " May, 1902.
Garfield. " " June and July, 1903.
Heyland. "Electrotechnische Zeitschrift," December 12, 1901; June 26, 1902.
" "Soc. Int. Electr. Bull.," July, 1902.
" "E.T.Z.," January and February, 1903.
Latour. "Industrie Electr.," February 25, March 10 and 25, 1902.
" "Eclairage Electr.," April 12, 1902.
" "Soc. Int. Electr. Bull.," May, 1902.
Leblanc. "Eclairage Electr.," December 2, 1899.
" "Zeitschr. Electrotechn." Wien, March 11, 1900.
" "Electrician," September 28, 1900.

Dr. W. E. SUMPNER, having congratulated Mr. Atchison on his paper, said many had written papers on advanced Alternating-Current Theory, and lately, at all events, many had written papers describing oscillograms taken with the oscillograph, but he did not think any one before had had the heroic courage to deal with the theory of alternating currents by means of the sine wave, and in the same paper give a great many oscillograms which showed clearly that no theory of alternating currents in which the sine wave was assumed could be satisfactory. Mr. Atchison had done that with regard to the power-factor. He did not know that there was any general agreement as to what was meant by the power-factor of a three-phase circuit. It was easy to give a definition if all the voltages were assumed equal and also all the currents equal, conditions which were never exactly fulfilled; but where the voltages and currents differed, he did not think any one had given a definition of the power-factor. Such a definition might be the following:—Suppose V to be the voltage between each main and the neutral point, or the mean of the three voltages if different, the volt-amperes of the circuit could then be defined as the product of V and the sum of the three currents in the mains; and the power-factor of the circuit would be the ratio of the watts to the volt-amperes so defined. Dr. Sumpner.

Considerations of this kind, together with the oscillograms given by

Dr. Sumpner. Mr. Atchison, made one very doubtful whether a good deal of the theory contained in this and other papers could be looked upon as reliable, the more so as a large number of constants had to be determined from experiment to make the theory work. Rothert's theory concerning ampere-turns was an instance. Similarly, though he was very much interested in Mr. Atchison's theory about two coefficients of self-induction of the armature, he thought the same criticism applied to that method. Dealing with the asynchronous generator, he questioned the statement made by Mr. Atchison that "the asynchronous machine has a definite power-factor for every load." In conclusion he recommended that oscillograph experiments, instead of being directed to investigate most interesting but exceptional cases, should preferably be used to explain what happened under ordinary working conditions, as, for instance, to explain the discrepancy between theory and actual results in the ratio of the voltage between the mains and the neutral and the voltage across the mains, in an ordinary three-phase circuit.

Dr. Morris. Dr. D. K. MORRIS said that, with reference to the theoretical part of the paper, it must be pleasing to engineers to see that Mr. Atchison had carried out an experimental investigation which went hand in hand with the theory. He had shown very clearly on four small, but different, alternators exactly the extent to which it was possible to predict the regulation. He would like to say a word or two on the general question of magnetising. It could not fail to strike any one who read a paper like this what an extraordinary proceeding it was to magnetise iron in the way that it was done in transformers and in induction motors. The energy wanted for magnetising was no more than that needed to overcome copper and iron losses; but, to effect magnetisation from alternating mains, the mere voltage corresponding to these losses was not enough to drive the magnetising current. A very much larger component of voltage was wanted—a quarter-phase in advance—merely because of the frequency at which the magnetising had to be effected. Hence arose all the troubles due to bad power-factor, and it was owing to Heyland and others that much progress had lately been made towards the solution of the problem of how to reduce, or even annihilate, the frequency at which the magnetising current had to do its duty, and so effect magnetisation rationally from an alternating source. He would like to ask whether Mr. Atchison had any experience with compounded alternators, for their properties led one to expect that they would run well in parallel. The remarks on parallel running of machines with different wave-forms suggested a comparison between the wave-form of the alternator itself and the cyclically varying mechanical effort of steam or gas engines. Mr. Atchison suggested that a difference of wave-form on two alternators running in parallel would give trouble. Was it not just such a difference of "effort form" on the part of the prime movers which usually caused defective parallel running, and was it not needed rather to require a certain similarity of effort, however irregular, than to specify the uniformity of the rotation of the alternator by the prime mover? Not only should the alternators be synchronised, but the engines should be in step also. The paper had put before them the present state of things with regard

to alternating-current work and the wonderfully interesting problems which were coming forward. Dr. Morris.

Mr. A. M. TAYLOR, referring to Dr. Sumpner's remarks on the mixing up of the armature reaction and the leakage flux in the armature, said he thought Mr. Atchison and those American writers whom he followed were warranted in combining the two effects if in practice it was found that the results agreed with the theory. He had not read the whole of the paper, but he understood that Mr. Atchison's experimental investigations on this point substantiated the assumption. Other writers, notably Mr. A. C. Eborall, kept the two quite distinct, and he (Mr. Taylor) preferred this from the point of view of simplicity. The asynchronous compounded generator seemed likely to be a very useful thing in the near future, and he would like to know whether the periodicity of the currents supplied from it remained constant with varying loads on the circuit. It seemed that a falling-off in the periodicity with increase of load would have bad results in the way of regulation on the secondary sides of the static transformers, and synchronous motors would no longer possess their valuable feature of going at constant speed, which was, for some industries, very essential. Mr. Taylor.

Mr. R. K. MORCOM welcomed the confirmation which the paper afforded of his own view that the engines were not always responsible for difficulties in parallel running. He could not, however, see in what way the adjustment of flywheel capacity would have the effect on resonance indicated in the paper, as it would not affect the periodicity of the engine's impulses. He thought it would be a very good thing if they had a standard definition of what the power-factor of a three-phase machine was. A trouble with some of these compounded alternators seemed to be bad sparking at the commutator. Mr. Morcom.

Mr. A. F. T. ATCHISON, in reply, said that he regretted that, owing to a delay in the printing of the paper, it had been impossible to circulate it beforehand to those desirous of joining in the discussion, and owing to its length he had been compelled to read much of it in an abbreviated form. In reply to Dr. Sumpner, he said that no assumption of the wave-forms being sine waves was made in the theoretical part of the paper, and that the oscillograms had, in fact, been introduced to show how incomplete the older sine-wave theories are when a closer examination is made into what is actually taking place in alternating-current circuits. He thought that the consideration of voltage drop under different loads, *i.e.*, the regulation, was to a great extent free from the objection to which so many other theories were open, namely, the incompleteness of the sine-wave theory; and that the subject of regulation might be dealt with by simply considering the actual waves replaced by sine waves of the same root-mean-square value and of the same frequency, and simply taking readings of your volts and amperes on the ordinary alternating-current instruments. Mr. Atchison.

The expression power-factor of "a three-phase circuit" was, however, a phrase to be avoided, since in such a system we have three complete circuits interlinked with each other; and if the system is

Mr. Atchison.

unbalanced, the power-factor of each phase must be considered, and the regulation of each phase will differ accordingly—the most heavily loaded phase, or that loaded on the lowest power-factor, showing worse regulation than the other two. As a matter of fact, all the regulation curves given in the paper were either single-phase curves or those of balanced polyphase loads. Dr. Sumpner's definition in the case of an unbalanced load was useful, as it gave the average power-factor of all the phases.

ORIGINAL COMMUNICATION.

EDDY CURRENTS IN SOLID AND LAMINATED MASSES.

By M. B. FIELD, Member.

If a long solid iron-core be surrounded by a magnetising coil which is traversed by an alternating current, the magnetic induction will be strongest at the bounding surface of the core, and may be practically zero in the interior. This is due to the action which the currents induced in the skin exert on the interior portions.

For example, if *a b c d*, Fig. 1, be the transverse section of a solid core, the magnetising current circulating at the moment in a clockwise direction around the exterior, the eddy currents that will be induced in the skin will circulate as indicated by the arrows, viz., in a counter-clockwise direction, and these will, in ordinary circumstances, as we shall see later on, exactly counterbalance the effect of the magnetising coil, producing practically zero magnetic force at the central portions of the core.

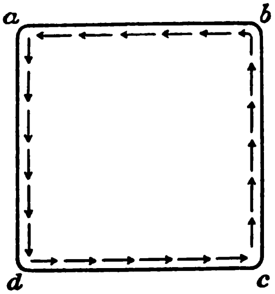


FIG. 1.—Plan.

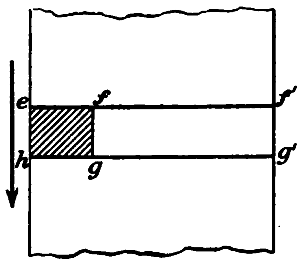


FIG. 2.—Elevation

Now let us consider a slice of the core comprised between two transverse planes 1 cm. apart, Fig. 2. The slice is chosen somewhere near the central portion, or at least sufficiently far from the ends to enable us to assume that the lines of induction are all parallel with the boundary. Let B_s be the value of the induction at any instant at the surface, μ the permeability, then the value of the magnetic force at the surface *e h* is $B_s/\mu = H_s$, its direction being taken as represented by the arrow.

Now the line-integral of magnetic force taken round any closed curve is $\frac{4\pi}{10}$ times the total current in amperes flowing through the area enclosed.

For the purpose of this investigation we will assume a positive

current as one going away from us into the paper, so that the direction of integration round the closed curve will be clockwise. We shall speak also of the magneto-motive force round the curve instead of the line-integral of magnetic force, in order to preserve the analogy with the electro-motive force taken round a closed circuit.

Consider the magneto-motive force round the shaded area $efgh$, Fig. 2; since the induction is normal to ef and gh the magneto-motive force e–f and g–h is zero. From h to e it is $-H_s$. Denote the M.M.F. from f to g by H_{fg}, then—

$$-H_s + H_{fg} = \frac{4\pi}{10} \times \text{total current flowing across shaded area.}$$

If we extend our shaded area right across the core, viz., $ef'g'h$, we know that the integral of current-density over the area is zero, hence

$$H_s = H_{f'g'},$$

that is, the magnetic force has the same value at both surfaces of the core.

Similarly, we see that, if the core were made up of a number of slabs as in Fig. 3 (the slabs being insulated, and no conducting matter being present between them), we should have

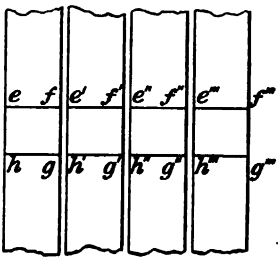


FIG. 3.

$$H_s = H_{fg} = H_{e'h'} = H_{f'g'}, \text{ etc.,}$$

that is, the induction would be the same at the surface of each lamina, and this would be the value it would reach at the surface of the core if solid.

It follows, therefore, that if we compare two similar cores, the one being solid, the other laminated, both being subjected to the same alternating magnetising agency, the maximum value of the induction-density reached will be found to be the same in each case, but the maximum value of the total flux will be very much greater in the laminated core than in the solid.

If we wished to consider the comparison, when the maximum total-flux value was the same in each case, it would be necessary to considerably increase the magnetising force in the case of the solid core, and this would involve the induction-density at the bounding surface being pushed to much higher limits in order to give the same mean value over the whole cross section as that obtained with the laminated core.

In considering, therefore, the eddy-current loss in such cores, we have to carefully distinguish between the two cases:—

(1) When they are subjected to a given alternating magnetic force, producing the same maximum value of the induction-density in both cores, but a larger total flux in the laminated than in the solid core;

(2) When they are subjected to such magnetising forces as will produce the same maximum total-flux value, or the same maximum value of the mean induction across the cross section of the core, this

involving a higher induction-density at the surface of the solid core than at the surface of the lamina.

These two cases are totally distinct, and must not be confused. An example of the first is to be found in the solid magnet limbs of motors, dynamos, alternators, etc., where, as shown recently by Dr. Thornton by means of oscillograms, definite alternating magnetising forces are exerted by the armature currents, the value of which would be the same whether the magnet limbs were laminated or not. The second case is exemplified in the armature cores, and in transformer cores, where, no matter what thickness of lamination may be employed, we have to force through a definite total flux to produce the E.M.F. or counter E.M.F., as the case may be.

Case I.

If we consider a plate of iron of thickness h cms. and permeability μ (assumed to be constant), subjected to an alternating magnetic force of which the maximum value at the surface of the plate is $\bar{H}_s$, the induction being in the plane of the plate, the loss in watts per sq. cm. of surface due to eddy currents is—

$$W = \cdot 315\,\rho\, m \left(\bar{H}_s\right)^2 \frac{\sinh mh - \sin mh}{\cosh mh + \cos mh} \quad . \quad . \quad . \quad . \quad (1)$$

where $m = 2\pi \,.\, 10^{-4}\sqrt{\dfrac{\sim\mu}{10\rho}}$ or $\cdot 000199\ \sqrt{\sim\mu/\rho}$,

and ρ = specific resistance of iron,

[N.B.—H_s denotes the instantaneous value of the sine function, and H_s the amplitude.]

one sq. cm. on each side of the plate being reckoned as two sq. cms. of surface area.

The mathematical theory * by which this result is obtained assumes constant permeability.

If $mh < 1$ we may expand the above expression in the form of a series; it is—

$$W = \cdot 0525\,\rho\, m^4 h^3 \left(H_s\right)^2 \left\{1 - \cdot 0405\, m^4 h^4 + \cdot 00166\, m^8 h^8, \text{etc.}\right\}$$

If now $mh < \cdot 75$ we may neglect all but the first term of the series, and we have, within $1\frac{1}{2}\%$ accuracy—

$$W\dagger = \cdot 0525\,\rho\, m^4 h^3 \left(\bar{H}_s\right)^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

whereas if $mh > 6$, equation (1) is equivalent to—

$$W = \cdot 315\,\rho\, m \left(\bar{H}_s\right)^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

We can express (2) in terms of watts per cub. cm. by dividing by $\frac{h}{2}$; it is—

$$\text{Watts per cub. cm.} = \cdot 105\,\rho\, m^4 h^2 \left(H_s\right)^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2\text{A}).$$

* See article by Prof. J. J. Thomson, *The Electrician*, April 8, 1892; the units we are employing are the practical units, watt, ampere, volt, etc.; those employed by Prof. J. J. Thomson are C.G.S. units.

† In the article referred to, Prof. Thomson's result for very thin plates is four times too large; evidently a slip has crept into the work.

Later on we shall consider the loss which occurs in a transverse slice of a laminated core of 1 cm. length, and we shall use this expression (2A) as the watts *per sq. cm. of core area,* since in this case each sq. cm. of core area represents 1 cub. cm. of core. With regard to the case where $mh > 6$, it is to be noted that the loss per sq. cm. of boundary surface is independent of the dimensions of the core, and we cannot therefore express this as watts per cub. cm. with any advantage.

In considering later the loss that occurs in the transverse slice of solid core between the two planes 1 cm. apart, we shall use expression (3) as the loss *per unit perimeter* of solid core, which is, in such a case, equivalent to "per sq. cm. of boundary surface."

This expression may be applied to the solid limbs of dynamo machines in certain cases, but in doing so it is necessary to use every caution against falling into serious error.

We must remember that in such cases we have two or more air-gaps in the magnetic circuit, and we have therefore to consider not only the magnetic force due to the magnetising ampere-turns, but also

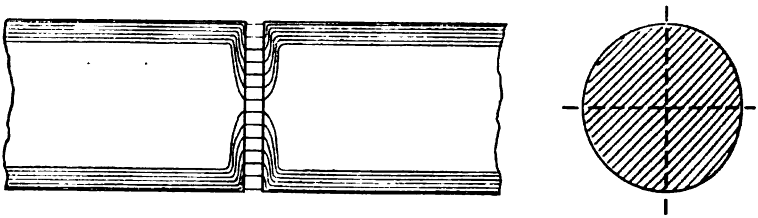


FIG. 4.

the demagnetising effect of the free magnetism spread over the polar surfaces. Then again, the limbs and yokes are not slabs pure and simple, but may have sharp corners, or ribs, or may be of other irregular cross section.

Let us form a picture of a magnetic circuit with a single air-gap, the iron being solid, and the area of the polar surface the same as that of the iron cross section, which is, let us say, such as would represent the magnet limb of a dynamo of not less than 10 k.w.

The circuit is magnetised with an alternating current of, say, 100 ∿ per second. We know then that the alternating magnetism will be confined to a skin of not more than 2 mm. depth (see curves below). The magnetic lines on reaching the polar surfaces will curl round, as shown in Fig. 4, and spread themselves more or less uniformly over the air-gap. A little consideration of the eddy currents induced in the polar surfaces shows us that here also the lines will be confined to a skin of very small depth, not very different from that at the side walls of the magnet limb. This leads to the twofold conclusion that the magnetic density in the air-gap at the polar surface is very small compared with that in the skin of the iron elsewhere, and hence the demagnetising effect of the air-gap will not be so great as may at first sight appear; and secondly, except in the immediate neighbourhood of

the polar surface or other sharp bends or corners, the magnetic lines may be taken as parallel with the bounding surface.

Again, since the eddy currents are confined to a skin of only about 2 mm. depth we may assume that the length of path at different depths within this skin does not vary. In such circumstances the following simple theory will be seen to hold good for all those portions of the magnet limb where the lines of force are parallel with each other, and with the bounding walls, and where no sudden change of shape of the boundary occurs. The plan and elevation of a small piece of boundary are represented in Fig. 5; in the plan view the arrows represent the eddy currents flowing parallel with the boundary (according to the convention above adopted, the direction of the arrows indicates a negative flow of current); hence, no E.M.F.'s are induced in planes normal to the boundary in this view.

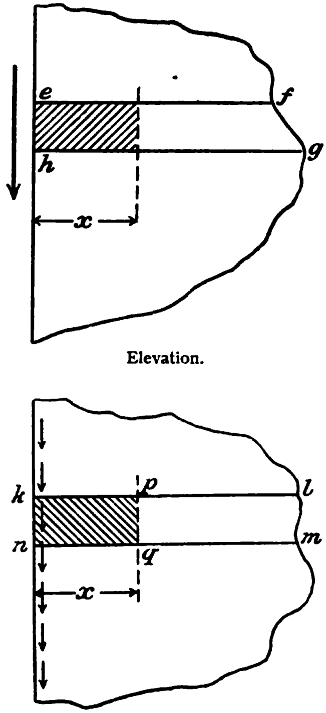


FIG. 5.

In the elevation the arrow shows the direction of the induction parallel with the boundary; hence in this view, no M.M.F.'s act in planes normal to the boundary and to the plane of the paper. Considering two planes through ef and hg respectively in the elevation, 1 cm. apart, we have, as already stated, the magnetic force at x cms. from the surface, given by the relation—

$$H_x - H_s = \frac{4\pi}{10} \times \text{ total current in amperes flowing across shaded area};$$

or expressing this as a differential equation, where A_x is the current-density at x in amperes per sq. cm. we have:

$$\frac{dH_x}{dx} = \frac{4\pi}{10} A_x \text{ or } \frac{dB_x}{dx} = \eta A_x \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

where $\eta = \frac{4\pi\mu}{10}$, and μ is considered constant. Again, considering in the plan view two planes 1 cm. apart, let N represent the total flux passing normally through the shaded area, then $-10^{-8}\frac{dN}{dt}$ is the E.M.F. generated in the perimeter $kpqn$. But no E.M.F.'s are generated in

the portions $k p$ and $n q$, hence if e_s is the E.M.F. generated from n to k, and e_x that from q to p, we have the relation—

$$e_x - e_s = \frac{d\,N}{d\,t}\,10^{-8};$$

or expressing this as a differential equation, we have—

$$\frac{d\,e_x}{d\,x} = \frac{d^2\,N}{dx,\,dt}\,10^{-8} = \frac{d\,B_x}{d\,t}\,10^{-8}.$$

Hence,
$$\rho\,\frac{d\,A_x}{d\,x} = \frac{d\,B_x}{d\,t}\,10^{-8} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

Eliminating B, we have
$$\rho\,\frac{10^8}{\eta}\,.\,\frac{d^2\,A_x}{d\,x^2} = \frac{d\,A_x}{d\,t} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

The solutions of these differential equations indicate an effect equivalent to a damped magnetic wave entering the iron from the exterior and becoming rapidly evanescent, the wave being reflected at any place where a sudden change of conditions occur, such as, for example, at a boundary.

In the case of an infinite solid there will be no reflection term. Now although the limbs we are dealing with are by no means infinite, the wave is damped down so rapidly that, for the purpose of this investigation, they constitute the equivalent of a solid of infinite thickness, and we may neglect all reflected waves.

The solution is, therefore, of the form:

$$A_x = \overline{A}_s\,\epsilon^{-mx}\sin(p\,t - m\,x)\,;\;\; B_x = \overline{B}_s\,\epsilon^{-mx}\sin\left(p\,t - m\,x - \frac{\pi}{4}\right);$$

$$\text{where } m = 10^{-4}\sqrt{\frac{p\,\eta}{2\,\rho}},\ \text{and } p = 2\,\pi \sim \quad . \quad . \quad . \quad . \quad (7)$$

The maximum values of the current-density, and induction at different depths below the skin are, therefore, $\overline{A}_s\,\epsilon^{-mx}$ and $\overline{B}_s\,\epsilon^{-mx}$, where $\overline{A}_s$ and $\overline{B}_s$ are the maximum surface values.

In Fig. 6 we have represented the way the induction strength falls off as we penetrate below the surface, the maximum values reached at different depths being plotted for four values of m, viz., 28, 14, 5·6 and 2·8. If we consider a wrought-iron limb and take $\mu = 2{,}000$, these values of m correspond to frequencies of 100, 25, 4, and 1 cycle per second respectively. For the case corresponding to 100 $\sim$ we see that the induction at 1·5 mm. below the surface does not reach one per cent. of the maximum surface value—the value reached by the current-density at any depth is proportional to the corresponding value of the induction at the same place, since both decrease according to the same law, hence we may, in the case of $m = 28$, take it that the whole eddy-current and magnetic effect is confined to a skin of not more than 1·5 to 2 mm. thickness. For lower frequencies the skin thickness will be greater, as shown by the curves in Fig. 6.

Equation (7) shows us that the magnetic effect is equivalent to a

wave * travelling inwards from the surface, the wave-length λ being $2\pi/m$. The maximum value reached by the induction and current density at a depth of one wave-length will be the surface value multiplied by $e^{-m\lambda}$ or $e^{-2\pi}$. This is ·00187, or less than $\frac{1}{500}$th of the surface value. We may, therefore, say the depth of penetration is less than one wave-length, if we agree to neglect such small values as $\frac{1}{500}$th of that at the surface.

The total current within the skin is, at any instant, per cm. length,

$$\int_0^\gamma \mathrm{A}_x dx = \frac{\bar{\mathrm{A}}_s}{\sqrt{2}\,m} \sin\left(pt - \frac{\pi}{4}\right);$$

and the total flux at any instant per cm. perimeter,

$$\int_0^\gamma \mathrm{B}_x dx = \frac{\bar{\mathrm{B}}_s}{\sqrt{2}\,m} \sin\left(pt - \frac{\pi}{2}\right),$$

where γ is a distance which is great relatively to the depth of magnetic

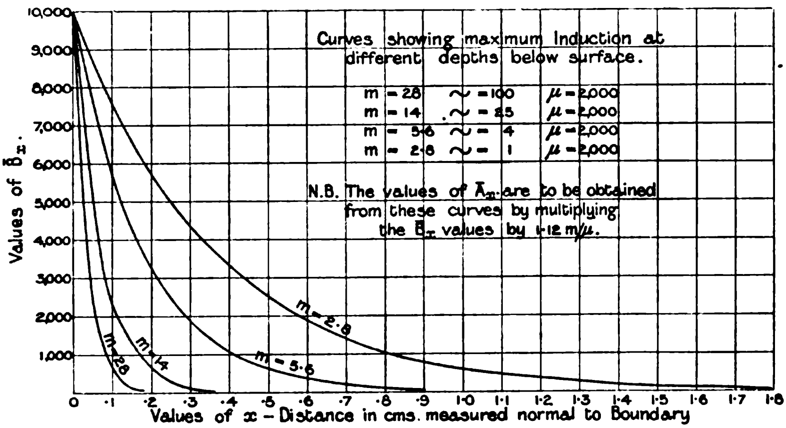


FIG. 6.

penetration. We shall call these vectors the total skin-current and total skin-flux, distinguishing them carefully from the surface current-density, and surface induction.

We see that the amplitudes of these vectors are so related, that the maximum values of skin-current and skin-flux are those which would be found in a skin $\frac{1}{\sqrt{2}\,m}$ centimetres thick if the surface values $\bar{\mathrm{A}}_s$ and $\bar{\mathrm{B}}_s$ were maintained constant throughout.

Referring back to the elevation view in Fig. 5, let the distance x be, say, one wave-length or more, then the total current through the

* More strictly a case of diffusion, the equations corresponding to those representing the diffusion of heat in a body when the exterior is alternately heated and cooled.

shaded area is the skin current per cm. length of core. Also we may take H_x zero, since x is so great that $B_x = o$; hence, $-H_s = \frac{4\pi}{10} \times$ skin current per cm. length of core: that is to say, the skin current at every instant produces a magnetic force equal and opposite to that at the surface.

Again, the E.M.F. per cm. of perimeter induced in the boundary surface is — the rate of change of the total skin flux, hence we have the connection—

$$\bar{A}_s = -\frac{\bar{B}_s}{\sqrt{2\,m}} \cdot \frac{10^{-8} p}{\rho};$$

we can therefore write down the following relations between the amplitudes of the various vectors :—

(1) The maximum value of the total skin-current is the current within a skin $\frac{1}{\sqrt{2\,m}}$ cms. thick, in which the current-density throughout is the same as the surface maximum value.

(2) The maximum value of the total skin-flux is the flux within a skin $\frac{1}{\sqrt{2\,m}}$ cms. thick, in which the induction throughout is the same as the surface maximum value.

(3) The maximum value of surface current-density equals the maximum value of total skin-flux $\times \frac{p\,10^{-8}}{\rho}$.

(4) The maximum value of surface induction equals the maximum value of total skin-current $\times \frac{4\pi\mu}{10}$.

The phase relation between these vectors has already been indicated.

The total eddy-current loss per sq. cm. of boundary surface is—

$$\frac{\rho}{2}\int_o^\gamma (\bar{A}_x)^2\,dx = \frac{(\bar{A}_s)^2\,\rho}{4\,m},$$

or that which would occur in a skin $\frac{1}{2\,m}$ cms. thick if the amplitude of the current-density at all depths within this skin were the same as the surface value.

The above relations allow of our writing the loss in watts per sq. cm. of surface in the following ways :—

Loss = vector product [surface induction] $\times$ [— surface current density] $\times \frac{\rho}{\eta}$.

$= $ surface current-density squared $\times \frac{\rho}{4\,m}$.

$= {\cdot}315\,\rho\,m\,(H_s)^2$, and since $m = 1{\cdot}99\;10^{-4}\sqrt{\frac{\mu \sim}{\rho}}$.

Loss $= 6{\cdot}27\;10^{-5}\,(\bar{B}_s)^2 \times \sqrt{\frac{\rho \sim}{\mu^3}}$.

In Fig. 7 we have plotted the losses per sq. cm. of boundary surface as a function of $\bar{B}_s$, corresponding to the same values of m as before. It will be observed that the loss in every case is very small; for example, taking an alternating induction which reaches 10,000 lines per sq. cm. at the surface, and alternates with a frequency of 100, the loss in watts per sq. cm. of surface is $2{\cdot}21 \times 10^{-3}$, so that the loss would only amount to 1 watt for every 450 sq. cms. of surface. The loss is proportional to m, that is to $\sqrt{\sim}$, other things being equal.

We now come to the comparison of two similar cores, the one solid, the other laminated, both being subjected to the same alternating magnetising agency; and we will confine our attention to a transverse slice 1 cm. long, taken where the lines of induction are parallel with the boundary. W_s and W_l denote the total watts lost

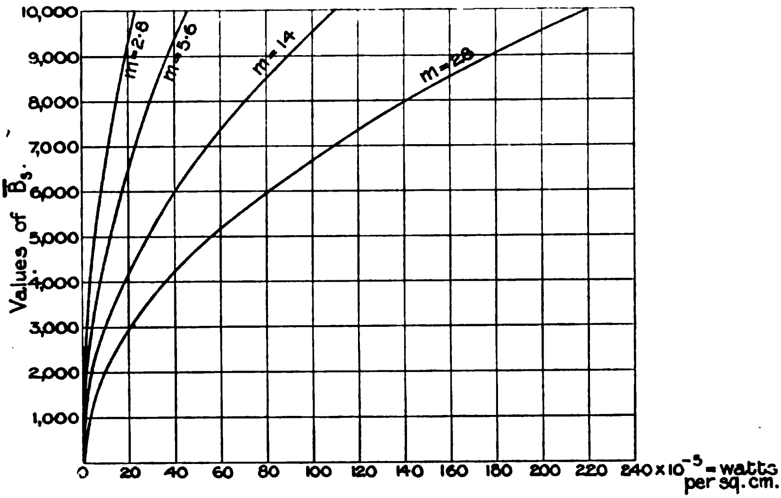


FIG. 7.

per cm. length of core in the two cases respectively, *i.e.*, the total watts due to eddy currents that occur within the transverse slice under consideration.

As we have already seen, W_s depends merely on the perimeter and not on the cross section of the core, since the loss per unit surface does not involve the dimensions of the core. We can therefore vary the area considerably without altering the perimeter, and therefore without altering W_s; in fact, this quantity will remain practically constant up to the point where the core has become a thin extended plate, whose thickness is comparable with the depth of magnetic penetration inwards from the two faces. We have also seen that if we subdivide our core into several slabs the induction in the skin of each slab will be the same as in the undivided core if subjected to the same magnetising agency, and the total watt-loss must be reckoned as $\cdot 315\, \rho m(\bar{H}_s)^2$ per cm. perimeter of all the slabs.

For example, if we consider a rectangular core cross section, the length of whose sides is a, the loss will be $W \times 4a$; whereas if this core be subdivided into three slabs, the total perimeter will be doubled and the loss will be accordingly $W \times 8a$, W being the loss per square cm. of surface. Hence we see that a coarse subdivision or lamination of a solid core will increase the eddy losses due to a given alternating magnetic force, in proportion as the total surface of all the laminæ is increased, provided of course that the subdivision is not carried so far that the thickness of lamination becomes comparable with the depth of magnetic penetration.

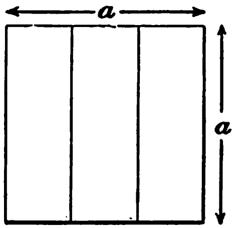


FIG. 7A.

If on the other hand we sufficiently laminate the core, the loss may be taken as proportional to the cross-sectional area and to h^2—see equation (2A)—and as independent of the perimeter.

Considering similarly shaped cross sections, we know that the area increases faster than the perimeter; hence it follows that however finely we may laminate, if we only make the cross-sectional area of the core large enough we shall come to a point when $W_l > W_s$.

It becomes, therefore, of interest to inquire for any given area what critical value of lamination thickness renders $W_l = W_s$. Clearly a smaller thickness than this critical value must be taken if any advantage is to be gained from lamination.

For laminæ, we have the loss per unit of side area equals

$$\cdot 315\,\rho\, m\,(\overline{H}_s)^2\,\frac{\sinh mh - \sin mh}{\cosh mh + \cos mh},$$

hence if a_1, a_2, a_3, etc., are the breadths of the successive laminæ,

$$W_l = \cdot 315\,\rho\, m\,(\overline{H}_s)^2\,\frac{\sinh mh - \sin mh}{\cosh mh + \cos mh}\, 2\,\Sigma\, a_1 + a_2 + a_3 + \text{etc.}$$

$$\text{But } 2\,\Sigma\, a_1 + a_2 + a_3 + \text{etc.} = \frac{\text{Total cross section}}{\text{Half thickness of lamination}} = \frac{S}{h/2}.$$

Further we know

$$W_s = \cdot 315\,\rho\, m\,(H_s)^2\, L, \quad \text{where L is the perimeter.}$$

$$\text{Hence} \qquad \frac{W_l}{W_s} = \frac{S}{L}\cdot\frac{2}{h}\,\frac{\sinh mh - \sin mh}{\cosh mh + \cos mh}.$$

If we denote $\frac{2}{h}\cdot\frac{\sinh mh - \sin mh}{\cosh mh + \cos mh}$ by $\frac{1}{k}$, we may say:—

$$\text{If } \frac{S}{L} = k \qquad W_l = W_s;$$

$$\text{If } \frac{S}{L} > k \qquad W_l > W_s;$$

$$\text{If } \frac{S}{L} < k \qquad W_l < W_s.$$

For any given value of m_1 which depends solely upon ρ, μ, $\sim$, we can plot a curve connecting h and k. Having plotted one curve for a particular value of m, say m_1, we can readily obtain a whole family of such curves; suppose, for example, we wish to obtain the curve corresponding to the value m_2, we take a particular value of h and k on the m_1 curve, multiply these values by $\frac{m_1}{m_2}$ and the results represent a point on the m_2 curve. In other words, if h_1 k_1 represent a point on the m_1 curve, $\frac{h_1 m_1}{m_2}$ and $\frac{k_1 m_1}{m_2}$ will be the corresponding values h_2 k_2 on the m_2 curve.

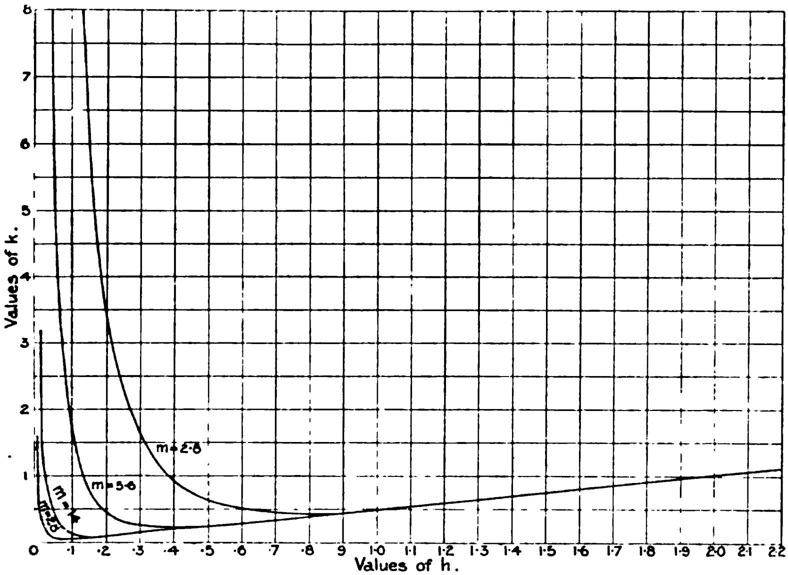


FIG. 8.

Fig. 8 represents the connection between h and k for the four values of m previously taken, viz., 28, 14, 5·6 and 2·8. It is clear that when $mh > 6 \quad k = h/2$; when $mh < \cdot 75 \; k = \frac{3}{m^3 h^2}$, since the expression $\frac{\sinh mh - \sin mh}{\cosh mh + \cos mh}$ can in these instances, as already explained, be replaced by unity and $\frac{1}{6} m^3 h^3$ respectively.

Let us take as an example a rectangular wrought-iron core 35 cm. × 20 cm., $\frac{S}{L} = 6 \cdot 4$. Referring to the curves we see that for the value $k = 6 \cdot 4$, if $m = 2 \cdot 8$ ($\sim = 1$) $h = \cdot 146$ cms. If $m = 28$ ($\sim$ 100) $h = \cdot 0046$ cms.

These are, then, the critical thicknesses of lamination corresponding to this size of core, and to the frequencies 1 and 100 respectively, which will give the same eddy-current loss as if the core were solid.

In both of these cases $mh < \cdot 75$, and in fact if we work out mh for all cases that occur in dynamo construction (except for very small machines or extraordinarily low frequencies), we shall find that it is less than ·75. In these circumstances $k = \frac{3}{m^3 h^2}$ or $h = \sqrt{\frac{3}{m^3 k}}$.

If in place of k we substitute $\frac{S}{L}$, a condition which gives $W_t = W_s$, we have $h = \sqrt{\frac{3L}{m^3 S}}$, provided $mh < \cdot 75$.

In the case of a square rectangular core of side length a, or circular cores of diameter a, we have $\frac{L}{S} = \frac{4}{a}$; hence in these instances $h = \frac{3\cdot 46}{\sqrt{a m^3}}$.

Example: Let $a = 10$ cms., $m = 28$; then $h = \cdot 00735$ cms. (·0735 mm.), $mh = \cdot 205$. Hence, with a 10 cm. diameter round core, laminations less than ·0735 mm. would have to be employed to give beneficial results.

In transformer manufacture the thickness of lamination is taken at about 0·3 mm., the gain by still further lamination being small, and the cost of manufacturing the plates great. But it appears that if a core be subjected to a given alternating magnetic force (a case of course not met with in transformers), a very much finer lamination will be necessary to lessen the eddy loss, unless, indeed, the frequency be very low.

Referring again to the core previously mentioned, 35 × 20 cms., assume the magnetising force is such as to produce an induction of 10,000 lines (max.) in the skin, and compare the losses in the two cases, (a) if solid, (b) if laminated; the thickness of lamination being ·3 mm., or $h = \cdot 03$. The following table gives the result, the losses being in watts per cm. length of core :—

∿	W_l	W_s
1	·0010	·024
8·25	·069	·069
12·5	·16	·085
25	·64	·12
50	2·54	·171
100	10·15	·242

We can express W_l as $W_s \times \frac{S}{L\,k}$; if now we draw a curve connecting h and $\frac{1}{k}$ for a given value of m, we see at a glance how many times W_l is greater than W_s for any particular thickness of lamination.

In Fig. 9 such curves are drawn for the same values of m as heretofore, and from these we see that with $m = 28$, if we choose a thickness of lamination of 0·8 mm. the loss in the 35 × 20 cm. core will be $6{\cdot}4 \times 23{\cdot}4 = 150$ times as great as if it were solid, always assuming, of course, the comparison is made between the two cores when $\bar{B}_s$ is the same in each, that is when both are subjected to the same alternating magnetic force. It is also clear that the hysteresis loss in a core

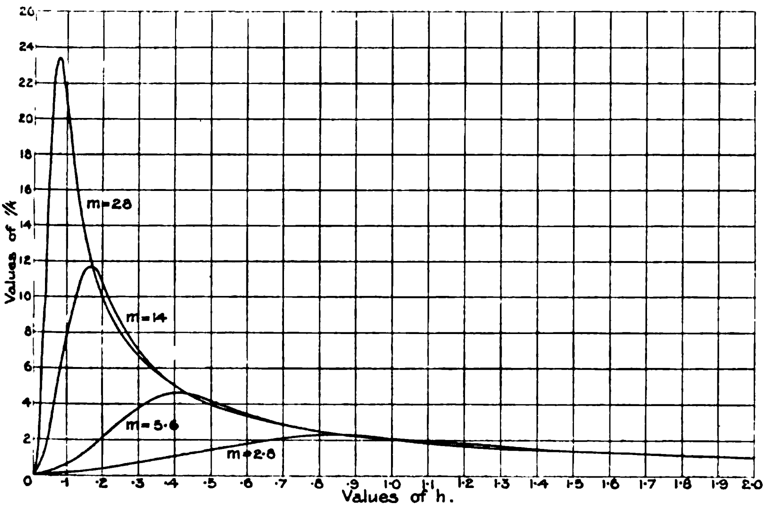


FIG. 9.

subjected to a given alternating magnetic force is increased by lamination, for while the maximum induction density remains the same in the laminated as in the solid, the total flux is much greater in the first than in the second, *i.e.*, more of the iron is subjected to the alternating induction. If the lamination be coarse ($mh > 6$), the hysteresis loss increases in the same proportion as does the eddy-current loss for a given frequency.

We have so far assumed constant permeability. If the maximum induction is kept well within the saturation limit, results worked out on this assumption will not be very wide of the truth. Again, if the core be already magnetised in a given direction by a constant magnetising agency, and a small alternating magnetic force be superimposed, the assumption of constant permeability is quite permissible, since in this case, as is well known, the hysteresis loops enclose comparatively small areas.

We will now consider roughly the effect of saturation in the outer skin of a solid core; this will be twofold—it will produce a smaller induction at the exterior surface, and it will cause the magnetism to penetrate to a greater depth into the interior. The total eddy loss will also be less. We will take the curve *a b c*, Fig. 10, as representing the maximum values reached by the induction at different depths below the surface, on the assumption of constant permeability, and assume that saturation really occurs about the value B_1. Let the magnetic force at this point be H_1 and at the surface H_s as before; then we have, at any instant,

$$H_1 - H_s = \frac{4\pi}{10} \times \text{current through shaded area.}$$

But since owing to saturation the mean current density over this area is less than that given by the assumption of constant permeability, the area must be larger, and the point *b* will be carried further into the interior. We should then get an induction curve something of the nature of that shown dotted in the annexed figure. Although this argument is approximately correct it is not rigorous, as it does not take account of the change of phase that occurs in the induction as it penetrates into the interior.

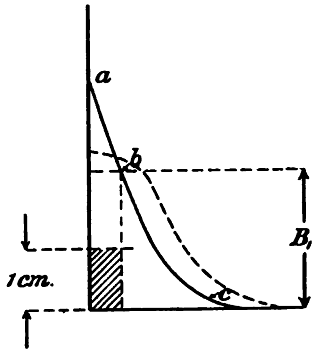


FIG. 10.

The magnetising coils that surround large cores are often wound upon metal formers, which virtually form short-circuited turns round the core. Alternating fluxes in the cores will induce currents in the formers, and generally the effect will be to decrease the total loss if subjected to a given alternating magnetic force, to increase it if subjected to such a magnetic force as will produce a given alternating total flux.

Let us consider a former closely fitting the core, the thickness of the former being τ cms., its specific resistance ρ_1, and its permeability unity. The whole current in the former, if thin, will be in phase with the surface current in the core, and its maximum value per cm. length will be $\bar{A}_s \tau \rho/\rho_1$, where $\bar{A}_s$ is the maximum value of the current-density at the core surface. The total core skin-current is $\bar{A}_s/\sqrt{2}\,m$, and these will differ in phase by the angle $\frac{\pi}{4}$, hence the amplitude of magnetic force external to the former is—

$$A_s \frac{\eta}{\mu} \sqrt{\frac{\tau^2 \rho^2}{\rho_1^2} + \frac{1}{2m^2} + \frac{\tau\rho}{\rho_1 m}}.$$

The total loss in former and core, per sq. cm. of core-surface, is—

$$\frac{(\bar{A}_s)^2 \rho}{2} \left(\frac{\tau \rho}{\rho_1} + \frac{1}{2m}\right),$$

and the total loss in the core without former, if subjected to the same magnetic force will be—

$$\frac{(\bar{A}_s^2)\rho}{2} \cdot m\left(\frac{\tau^2\rho^2}{\rho_1^2} + \frac{1}{2m^2} + \frac{\tau\rho}{\rho_1 m}\right).$$

It will be useful to compare these expressions.

Let us take $\bar{B}_s$ with the former in position equal to 1000, $m = 28$ $\rho = 10^{-5}$, $\rho_1 = 5 \times 10^{-6}$, $\tau = \cdot 2$ cm.

Then we have $\bar{A}_s = 15{\cdot}9$ amperes per sq. cm.; current per cm. length of former $= 6{\cdot}34$ amperes maximum. Core loss $= 2{\cdot}22\ 10^{-5}$. Former loss $= 5{\cdot}02 \times 10^{-4}$ watts per sq. cm. Total loss $= 5{\cdot}24\ 10^{-4}$.

The magnetic force at the core surface is to the magnetic force external to the former in the ratio $\frac{1}{\sqrt{2m}} : \sqrt{\frac{\tau^2\rho^2}{\rho_1^2} + \frac{1}{2m^2} + \frac{\tau\rho}{\rho_1 m}}$, or as $1 : 16{\cdot}6$, hence without the former the core loss would be $2{\cdot}22\ 10^{-5} \times 16{\cdot}6^2 = 61{\cdot}2\ 10^{-4}$; that is to say, the presence of the former reduces the total loss to about $\frac{1}{12}$th of the value it would otherwise attain. Again, with the former present, $\bar{B}_s$ was taken as 1000, but without the former, assuming the same value of μ, the surface induction would rise to 16,600 maximum, or to approximately the saturation point.

Owing to the shielding effect of the skin on the interior portions, it is clear that if the core area be large enough we shall come to a point where the maximum value of the mean induction over the cross section, divided by the maximum value of the magnetic force at the surface is less than unity. This may be called the mean effective permeability, μ_e, and when this is less than unity the core will behave, as a whole, as though it were diamagnetic. We can see what the conditions are which render $\mu_e < 1$.

The total flux in the core is $\frac{\bar{B}_s}{\sqrt{2m}} L$, where L is the perimeter; and the external magnetic force H_s is B_s/μ. The flux that this would produce in an air core of area S is $\frac{B_s}{\mu} S$; hence $\mu_e = \frac{L}{S} \cdot \frac{\mu}{\sqrt{2m}}$.

Now if we consider circular or square cores of which the diameter, or side as the case may be, is a, we have $\frac{L}{S} = \frac{4}{a}$; hence if

$$\frac{a}{4} > \frac{\mu}{\sqrt{2m}}, \ \mu_e < 1.$$

For example, if $\mu = 2{,}000$, $m = 28$ ($\sim = 100$), and the mean effective permeability will be less than unity if $a > 200$ cms.

If the frequency be increased, the core area that will give $\mu_e < 1$ decreases: for example, if we consider a thin plate of thickness $\cdot 3$ mm. $\frac{S}{L} = \cdot 015$, and the value of m which gives $\mu_e = 1$ is 94,000, corresponding to a frequency of 11×10^8 cycles per second. This is of interest in

connection with the question of employing iron in choking coils for arresting high-frequency oscillations.*

It is well known that iron filings will arrange themselves in concentric circles around a wire through which a Leyden jar discharge passes: in this case the frequency is very great, but not sufficient to cause the iron particles to behave as diamagnetic bodies on account of their extreme smallness. Suppose we consider them as cylindrical, of diameter ·01 cm. and of considerable length in comparison, then for $\mu_e = 1$ we should have, when placed with their axes parallel with the magnetic force—

$$\cdot 0025 = \frac{\mu}{\sqrt{2m}}, \text{ or say } m = 5\cdot 65\ 10^5;$$

which means an excessively high frequency. In both of these instances our rule is applicable, because in spite of the small dimensions of the solids, on account of the extreme frequency the depth of penetration is exceedingly small compared with the dimensions of the solid.

If we consider metallic bodies for which $\mu = 1$, we see that for any frequency the effect of the induced currents in them will be to cause them to behave virtually as diamagnetic substances in so far as $\mu_e < 1$. This phenomenon is made use of in practice in many ways; one of great interest may here be mentioned, viz., the method employed by meter manufacturers for magnetising the permanent magnets employed.

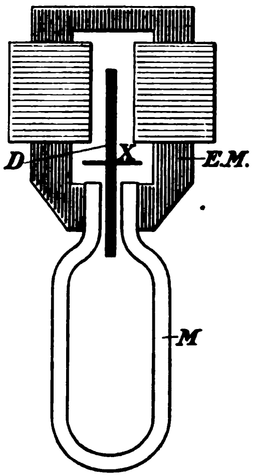


FIG. 11.

E.M., Fig. 11, is an electromagnet energised by a continuous current; M is the permanent magnet to be magnetised; D is a rotating copper disc, rotating about the axis X. The effect of the currents induced in the copper causes μ_e for the space occupied by the disc to be less than unity; hence, instead of the lines of force merely passing across the air-gap, they are forced to take the path offered them by the permanent magnet M, which thus becomes polarised.

Returning now to the solid cores of dynamo-machines, we will consider the effect of irregularity of section of the armature, or the effect of a periodically varying air-gap.

Assume that the area of the air-gap is that of the core cross section,

* It must be remembered that we define μ_e as $\frac{\overline{B}_m}{H_s}$, where $\overline{B}_m$ is the maximum value of the mean induction over the cross section. The vectors representing the magnetic force at the surface and the mean induction over the cross section differ in phase by the time-angle $\frac{\pi}{4}$.

and the length is δ cms. If B is the value of the induction in the air space (supposed uniform), the demagnetising effect expressed in ampere-turns is—

$$\frac{B\,\delta}{1\cdot 26}.$$

If, now, the air-gap vary periodically, we shall have an effect which could be exactly imitated by keeping the air-gap constant and superimposing a magnetising force varying in a certain definite periodical manner.

Suppose, as is the case in a dynamo, the circuit be already magnetised by a continuous current and the air-gap be periodically varied; let it be, say, $\delta = \delta_1 (1 + \gamma \sin kt)$. Suppose further that l is the length of the iron path, and that a magnetising agency of

$$\frac{B}{1\cdot 26}\left\{\frac{l}{\mu} + \delta_1 (1 + \gamma \sin kt)\right\} \text{ ampere-turns}$$

be applied to the circuit: clearly the uniform induction B would be maintained in spite of the varying air-gap. If now the applied magnetising ampere-turns were $\frac{B}{1\cdot 26}\left\{\frac{l}{\mu} + \delta_1\right\}$ we should again have the constant induction B throughout the circuit provided the air-gap was constant at its mean value. The extra magnetising ampere-turns $\frac{B\,\delta_1\,\gamma \sin kt}{1\cdot 26}$ are therefore necessary to maintain B constant in spite of the variation of the air-gap. The effect of the variation of the air-gap is therefore *nearly but not quite* a demagnetising force equal to $\frac{B\,\delta_1\,\gamma \sin kt}{1\cdot 26}$ ampere-turns.

The result of this can very readily be seen; as a rule it is small. Let us take $B = 5{,}000$ $\delta_1 \gamma = \cdot 0252$ cms. Then the maximum value of this demagnetising force in ampere-turns is 100. If now the variation of the air-gap be rapid, the frequency of this demagnetising force will be correspondingly great, and the flux which it will give rise to will exist only in the skin of the solid portions of the magnetic circuit. It is of course useless to go into any minute calculations in this respect, since the results are wholly dependent on the nature of the distortion of the armature; and even if the air-gap varies harmonically, the above simple rule is not strictly correct. The above calculation suffices, however, to indicate that the effect of a varying air-gap in an ordinary dynamo cannot represent more than a varying magnetic force equivalent to something of the order of 100 ampere-turns applied to the whole magnetic circuit, and therefore cannot give rise to serious losses. In the case of a quickly and periodically varying air-gap it is quite incorrect, of course, to assume that the total induction varies between the same limits as does the total magnetic reluctance of the circuit.

CASE II.

We now come to the consideration of cores where we require a given mean induction across the cross section. It is easily proved that

in the case of laminations, the mean value of the induction across the laminæ, when the total flux is a maximum, is—

$$\bar{B}_m = \frac{\sqrt{2\mu}\,\bar{H}_s}{mh}\sqrt{\frac{\cosh mh - \cos mh}{\cosh mh + \cos mh}};$$

$$\text{or}\quad \bar{H}_s = \frac{mh}{\sqrt{2\mu}}\,\bar{B}_m\sqrt{\frac{\cosh mh + \cos mh}{\cosh mh - \cos mh}}.$$

Hence, combining this with equation (1), we get for the eddy loss in watts *per cub. cm.* expressed in terms of the maximum mean induction across the lamina,

$$\cdot 315\,\rho\,\frac{m^3 h}{\mu^2}\left(\bar{B}_m\right)^2\frac{\sinh mh - \sin mh}{\cosh mh - \cos mh}.$$

We can expand $\dfrac{\sinh mh - \sin mh}{\cosh mh - \cos mh}$ in the form of a series, it is:

$$\frac{mh}{3}\left[1 - 1\cdot 59\ 10^{-3}\,m^4 h^4 + 4\ 10^{-6}\,m^8 h^8 - \text{etc.}\right].$$

Hence we may write the loss per cub. cm. as—

$$\cdot 105\,\frac{\rho\,m^4 h^2}{\mu^2}\left(\bar{B}_m\right)^2\left[1 - 1\cdot 59\ 10^{-3}\,m^4 h^4 + 4\ 10^{-6}\,m^8 h^8 - \text{etc.}\right].$$

If now $mh < 1\cdot 5$, we may neglect all but the first term of the series, whereas if $mh > 6$, we may replace the series by $\frac{3}{mh}$. Hence, for very thin laminæ $W = \dfrac{\cdot 105\,\rho\,m^4 h^2}{\mu^2}\left(\bar{B}^2_m\right)$, and for thick laminations $W = \dfrac{\cdot 315\,\rho\,m^3 h}{\mu^2}\,\bar{B}^2_m$, where $\bar{B}_m$ is the maximum mean induction, these formulæ holding merely so long as the maximum surface induction is not beyond the limit of saturation.

It will be observed that in the case of thin plates the mean may be taken the same as the surface induction, and we may replace B^2_m/μ^2 by (H_s^2), which gives us the same formula as that previously given for thin plates, equation (2).

We see also that there is no critical thickness of lamination which gives a maximum loss, provided the case is one where we have to keep B_m constant, but that the finer the lamination the smaller the loss. This is the case under which all transformer, alternator, and dynamo armature cores come.

We have now dealt with all but one of the various important causes which may give rise to eddy currents in the solid portions of dynamos; the one remaining is the eddy loss in the pole-faces due to the armature teeth. The calculation of the eddy loss from this cause is not at all simple, and cannot be done by any of the foregoing methods. Heretofore the eddy currents have, so to speak, been forced to take definite paths parallel with a boundary. Knowing the form of the eddy-current path, we could readily calculate the various required quantities. But there are other eddy-current problems requiring

totally different treatment, namely, where eddy currents are induced in masses and are free to distribute themselves unhindered by boundaries. Such a case is met with in the damping copper disc in a Thomson-meter, eddy currents in pole-faces of dynamos, and other cases innumerable. With regard to the eddy currents produced by the armature teeth, we know by experience that lamination of the pole-faces materially reduces the loss; and indeed this is not surprising when we consider that of the two cases postulated, viz. eddies due to a given magnetic force, and eddies due to a given total flux, the polar-face loss seems to belong to the latter rather than the former, since a given definite total flux has to pass from the polar surface into the teeth.

In conclusion, it may be said that theoretical considerations show us that the loss in the solid parts of dynamo machines due to eddy currents (excepting the pole-faces) is not a serious quantity, and cannot affect the efficiency of the machine materially, and no advantage, but rather a disadvantage, is to be derived from laminating these portions.

These conclusions appear to the author to be diametrically opposed to those arrived at by Dr. Thornton, and published by him in the paper already referred to.

It must, however, be remembered that mechanical considerations may dictate the advisability of laminating certain portions of dynamo machines, which electrically would be left better solid.

For example, where excessive centrifugal forces arise, owing either to high speeds or the large revolving masses which are necessitated by some special design, it is sometimes found advisable to laminate the magnet frame to ensure that all parts take up their right proportion of the stress. Again, it is often cheaper to build both pole and pole-shoe laminated, than to attach a laminated pole-shoe to a solid pole; and again, for very small-sized motors, some makers claim that they are able to build a lighter and cheaper machine by constructing the whole-magnet frame out of stampings than is possible if castings be employed. Such considerations are, of course, entirely distinct from the purely electrical questions discussed in this communication.

ARMATURE REACTIONS IN ALTERNATORS, WITH SOME NOTES ON THE RUNNING OF SYNCHRONOUS MOTORS.

By H. W. TAYLOR, Student.

(*Abstract of Paper read before Students' Section, April* 20, 1904.)

INTRODUCTORY.

There are two ways of specifying the regulation of a machine, viz.:—

(1) That the voltage shall not *drop* more than a certain percentage when the load is changed from no load to full load, and
(2) That the voltage shall not *rise* more than a certain percentage above full-load value when full load is switched off.

The second method has been recommended by the American Institute of Electrical Engineers.

Reasons may be given for the use of either method, for while it is injurious to work lamps above their rated voltage, it is disadvantageous to work motors below this. It should be noticed that the percentage drop of (1) and the percentage rise of (2) do not bear any fixed relation to one another, their respective values depending on the part of the saturation curve at which the machine is working. As, however, the former is always greater than the latter, it would seem better to use that as a standard method of specification.*

For the purpose of design of the magnet coils and regulating rheostat, the regulation of a machine may be further expressed by the extra exciting current necessary at full load to maintain the same voltage as at no load.

GENERAL CONSIDERATIONS OF REACTIONS.

The current flowing through the coils of an alternator produces two effects. First, it acts on the main flux, always distorting it, and generally altering its value, according to the power-factor. Secondly, this action of the armature current on the flux produces an action on the coils themselves, which effect is, of course, self-induction.

These two effects will now be considered in detail.

(i.) *The magnetising action of the armature* is best considered by help of the conception used by Ferraris that an alternating quantity can be split up into two oppositely rotating quantities, each of a constant magnitude equal to half the maximum value of the alternating quantity, and each with a speed of rotation corresponding to the frequency of the alternating quantity. In the case of a single-phase alternator giving current, each coil is the seat of an alternating M.M.F., which may be split up, as stated, into two constant rotating M.M.F.'s as described;

* See a letter by Miles Walker in *Electrician*, vol. lii., p. 747.

but as the coils are moving with respect to the poles at the same rate as that at which these constant M.M.F.'s are moving with respect to the coils, one M.M.F. will remain *stationary* with respect to the poles, while the other will revolve twice as fast with respect to the poles as it revolves with respect to the coils. The actual position of the stationary M.M.F. with respect to the pole is that at which the maximum value of the alternating current occurs, and will be different for different power-factors.

Fig. 1 shows the positions where maximum current occurs for different power-factors. The ratio of pole-arc to pole-pitch, as here shown, is 0·66. In the case of multiphase machines, each phase will produce a pair of M.M.F.'s; and if the system is balanced, the stationary components of the different phases will all fall in the *same* position, while the double-speed rotating components will follow one another round the armature at equal intervals.

The stationary M.M.F.'s produce a permanent alteration in the main flux, both in value and in distribution, while the rotating M.M.F.'s produce periodic changes, at some times magnetising and at others

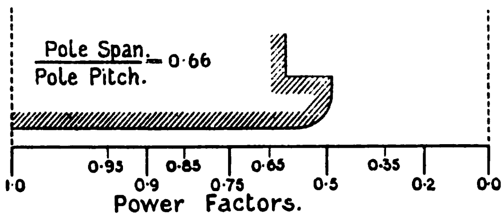


FIG. 1.

demagnetising, the average effect being *nil* except in so far as in magnetising they produce saturation.

There are two ways in common use of determining the resultant effect of the field M.M.F. and the armature M.M.F., viz.:—

(1) To combine them together as vectors which are separated in direction by an angle ϕ, where cos ϕ is the power-factor, and

(2) To take a component of the field M.M.F depending on the power-factor, and then to add this arithmetically to the field M.M.F.

With regard to the first method, the author is of opinion that this is an entirely erroneous procedure, as the field and armature M.M.F.'s in alternators cannot in any way be regarded as vectors. They are not vectors in space, because the direction of the flux produced by their joint action is defined by the shape of the magnetic circuit (the field magnet system is not a continuous ring of iron, as in an induction motor), and they are not vectors in time, because they are both constant quantities.

It is true that the flux is distorted in the pole-piece, and one writer has proposed to combine vectorially with the armature ampere-turns only those on the magnet coils which are necessary for the pole-shoe and gap; but this is hardly admissible, as, owing to the great difference

in permeability of the iron and the air, the lines emerge into the gap normally to the iron.

The second method, then, appears to be the more accurate, and in using it the active component of the armature ampere-turns is generally taken as proportional to sin ψ, where ψ is the *internal* phase angle, *i.e.*, the angle between the current and the generated volts, ϕ of course being the external phase angle, *i.e.*, the angle between the current and the terminal volts (see Fig. 5).

This of course is an assumption, for taking the case in Fig. 1, for all power-factors below about 0·5, the whole of the armature ampere-turns act directly on the field ampere-turns, just as if the armature coils were lifted up from the armature on to the field coils. A more accurate expression for the active component of the armature ampere-turns would, however, be difficult to calculate, but a method is suggested on page 1152 for arriving at it experimentally.

Considering the various principles which have been discussed above, the expression for the active component of the armature ampere-turns will be of the form—

$$0{\cdot}71 \times A\,T \times f(\psi) \times v;$$

where A = virtual amperes per phase;
T = number of turns per pole in all phases;
v = the usual leakage coefficient of the magnets (for one ampere-turn on the armature corresponds to v ampere-turns on the magnets);
and $f(\psi)$ is generally taken as sin ψ, but is really a more complex function depending on the ratio of pole-arc to pole-pitch, the pitches of the various coils, etc.

(ii.) *The self-induction of an alternator* is a very variable quantity. It varies for different excitations, for different values of the armature current, and, further, has a different value for each power-factor at which the machine is working. To get what is known as the stand-still coefficient of self-induction of an alternator, an alternating current of the proper frequency is sent through the armature while it is at rest, full exciting current being sent round the magnet coils. The voltage is measured at the terminals, and if the resistance is known, the coefficient of self-induction (L) is calculated from the well-known formula—

$$C = \frac{E}{\sqrt{R^2 + p^2L^2}}.$$

This is done for different positions of the armature with respect to the poles, and when the results are plotted a wavy curve is obtained, which repeats itself twice in one alternator period, as shown in Fig. 2.* The position for maximum self-induction may occur at the mid-pole or mid-between pole positions, according to whether the armature slots are open or closed, and according to the saturation of the armature teeth.

Having got the values of L for different pole positions, the average

* See *Electrical World*, vol. xli., p. 13.

value is usually taken as that to be used when the machine is working; but if necessary, a more strictly accurate result can be obtained by the following method. When the alternator is working, the current as well as the self-induction varies for different angular positions; but while the self-induction may be taken as constant for any one position, the current in the conductors at that position depends upon the power-factor.

The instantaneous value of the voltage drop due to self-induction is given by $L_0 \frac{di}{dt}$, so that if we take a virtual value of the instantaneous values of $L_0 \cos\psi$, we shall more nearly approximate to the voltage drop in the running machine. Fig. 3 gives an illustration, the curve

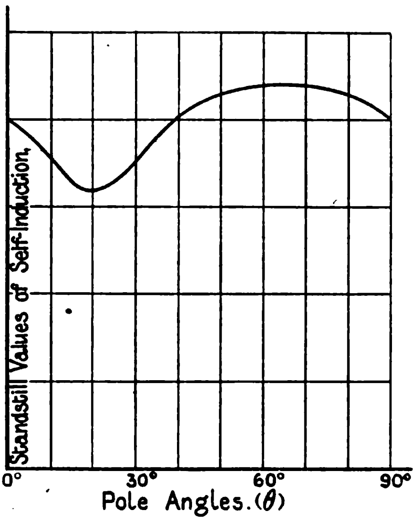


FIG. 2.

A and B having been obtained by multiplying the ordinates of the standstill curve by those of half-sine curves, whose maximum and zero values occur respectively at the position of maximum standstill self-induction. Fig. 4 was obtained by doing this with sine curves in a number of other different positions corresponding to other power-factors and taking the virtual value of the resulting curves.

Processes have been given by various writers* for calculating the coefficient of self-induction beforehand; but taking into account how intricately it is influenced by points in the design, only approximate results may be expected.

* Parshall and Hobart, *Engineering*, vol. lxx., 1900; Hobart and Punga, *Trans. Am. I.E.E.*, vol. xxi., p. 183, February, 1904; C. A. Adams, *Harvard Engineering Journal*, vol. i. pp. 145, 254, ii. p. 55; Arnold and La Cour, *Sammlung elektrotechnischer Vorträge*, band. iii., heft 1/3, p. 84; Hawkins and Wallis, *The Dynamo*, 3rd ed., p. 799.

DETERMINATION OF REGULATION WHEN REACTIONS ARE KNOWN.

The manner in which the regulation is calculated when the reactions are known (either from calculation or experiment) is shown in Fig. 5. At no load, the excitation O A is necessary to produce the

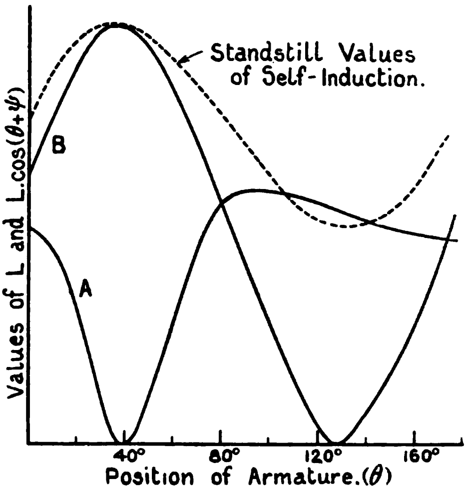


FIG. 3.

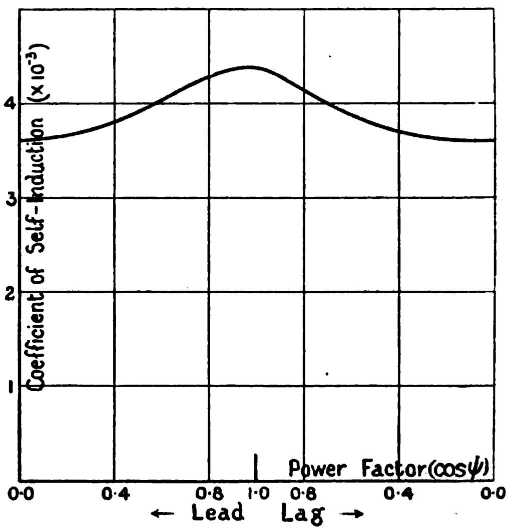


FIG. 4.

volts A D. The drop due to self-induction at full load is plotted out as D E at the proper angle, and at right angles to this, E F, the drop due to resistance (which, however, may usually be neglected) is drawn. To

generate the total voltage A F (= A G = A H) at no load a flux corresponding to the excitation O B is necessary; but if B C corresponds to the back magnetomotive force of the armature at full load, the amperes O C are required at full load to produce the same flux as O B at no load, and therefore to produce the generated volts A H, which give the terminal voltage A D at full load. Therefore, K is a point on the curve connecting terminal volts and amperes excitation at full load, and if full load is thrown off at this point, the terminal voltage will rise to C L.

The Short-Circuit Curves.

(1) *Preliminary Remarks.* — Behn-Eschenburg and many other writers have used this curve in their methods for determining the

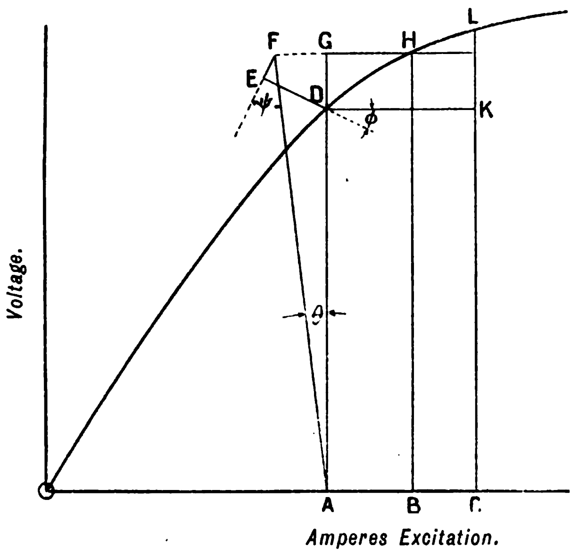


Fig. 5.

regulation on different loads. Although the curve cannot be predicted beforehand any more than the reactions can be predicted beforehand, it provides a ready means of testing large alternators where the power necessary for operating them at full load is not available until they are installed in the station and are ready for service.

Great care must be exercised in making a short-circuit test, as large errors are easily introduced. The ammeters used must have negligible resistance and self-induction, and it is advisable to get rid of permanent magnetism in the machine as far as possible.

(2) *Theory of Short-Circuit Curve.*—In considering the short-circuit curve, the exciting current is usually considered as the independent variable, but it will be found easier to understand if the problem is approached from the short-circuit current point of view and the

problem stated thus: For a given short-circuit current, what excitation is necessary?

In Fig. 6 consider any value of the short-circuit current, O C. This current produces a demagnetising action, and an equivalent number of amperes must be sent round the magnet coils to compensate for it. These are of course proportional to the short-circuit amperes, and in Fig. 6 are represented by the straight line O P. Next consider the voltage which must be generated to send the current against the self-induction (resistance being considered negligible) of the armature. From the no-load saturation curve the excitation necessary to produce this voltage is found, and is added to the excitation already plotted out (as A B = A'B', where O A is the voltage necessary for the short-circuit current O C). The point B' is then a point on the short-circuit curve.

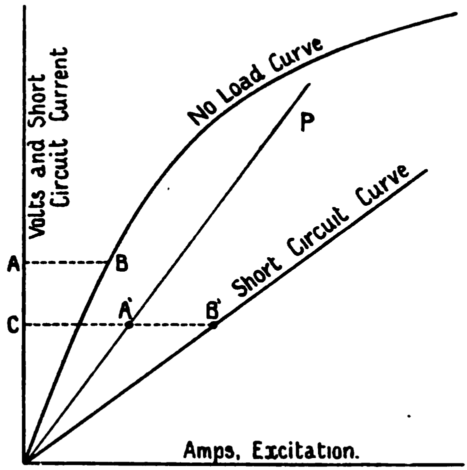


FIG. 6.

With regard to the shape of the last component of the short-circuit curve, the coefficient of self-induction of the armature decreases at higher excitations, and therefore the voltage required for the current is less than proportional to the short-circuit current. This would mean that the short-circuit curve would bend up away from the excitation axis if the no-load curve were a straight line, *i.e.*, if the pieces such as A B were proportional to the voltages to be dealt with. But the pieces A B increase more quickly than the voltage, and so the combined effect of saturation is to keep the short-circuit curve more nearly a straight line. Whether the curve finally bends up or down depends upon the relative saturations of the teeth and pole-tips, and the other parts of the magnetic circuit. An example of a short-circuit curve turning up has been given by Mr. Eborall in his Howard Lectures (Society of Arts), page 23, and an example of one turning down by Mr. Behrend in his paper before the American Institution last year.

(3) *Applications of the Short-Circuit Curve.*—The two simplest methods of using the short-circuit curve are deduced by supposing that all the armature reactions may be reduced either to an equivalent magnetising effect or to an equivalent self-induction.* Mr. Behrend, in his papers on the subject, † has discussed these methods very thoroughly, and it need only be pointed out here that except in the cases of certain abnormal types of machines, neither method gives accurate results.‡

The correct method to use the curve would be to analyse it into the two components already indicated in the previous section. In Fig. 7, O A is the necessary excitation necessary to produce the full-load value of short-circuit current. From A is plotted backwards A D, which corresponds to the actual demagnetising produced by the current O C. Then O D is the part of the exciting current which

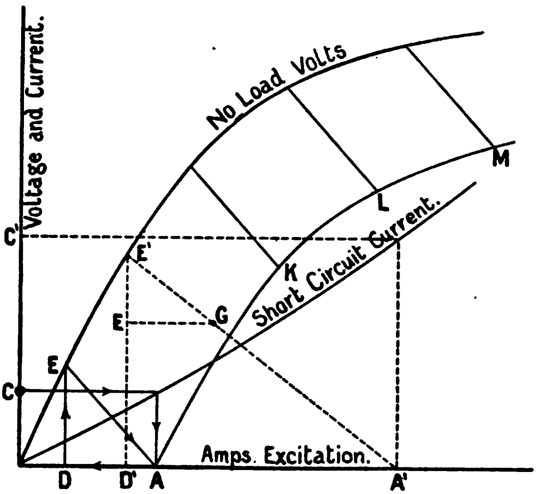


FIG. 7.

actually produces flux, and therefore the volts generated (and absorbed in armature self-induction) are O E. Then to a first approximation, the characteristic for a fully inductive full-load current is obtained by moving the no-load curve in the direction E A until the position A K L M is reached. For a nearer approximation the construction is repeated for a number of other short-circuit currents, such points as G being obtained by dividing such lines as E'A' in the ratio O C to O C'.

(4) *The Partial Short-Circuit Curve.*—To proceed with the foregoing

* This method is generally known as the synchronous impedance method.

† *Electrical World*, vol. xxxv., pp. 90, 120, and 166, 1900; *Trans. Am. I.E.E.*, vol. xx., p. 739, 1903; *Electrician* (London), vol. lii., p. 410.

‡ It should be noted that no method of pressure drop predetermination which is based *entirely* on the short-circuit curve can be absolutely reliable, as the conditions then existing in both the field magnets and the armature are exactly the reverse to those existing on a load.

construction, it is necessary to know either the self-inductive drop produced by the current, or the demagnetisation it causes. A method has already been given for calculating the self-induction of the armature in different cases. The following is a method for determining the demagnetising action, and because it is much quicker than the method for finding self-induction, it is perhaps more useful.

After the ordinary short-circuit test, another is made in which only one phase is shorted, the voltage on an open phase is read, and a set of curves as shown in Fig. 8 is obtained. At any excitation O A the short-circuit current for the one phase is O C, and as the volts A B are generated on the open phase, they are therefore also generated on the shorted phase. The equivalent excitation to generate these volts

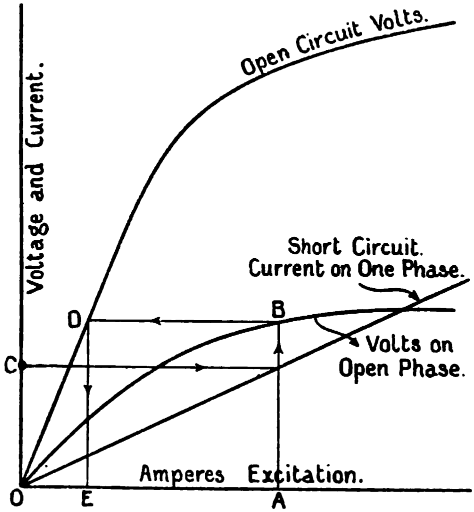


Fig. 8.

(A B = E D) is O E', so that of the total excitation O A, E A is counteracted by the armature current, and therefore E A are the amperes on the magnet coils which correspond to the current O C on the armature.

This test may be made on all polyphase machines, but obviously not on single-phase machines.

(5) *The Short-Circuit Curve for Different Frequencies at Constant Excitation.*—On page 1146 it was stated that at power-factors other than zero, the demagnetising action of the armature current was taken as proportional to sin ψ. In order to obtain a more exact relation, the following experiment is suggested: The machine is run at a number of different speeds, and short-circuit readings are taken with a constant excitation. The curve plotted between the values of frequency and current is of the shape shown in (1) Fig. 9. At low frequencies it is fairly steep and straight, but after a time it bends over and finally

becomes quite flat. Now the current is governed by the equation $C = \frac{E}{\sqrt{R^2 + p^2L^2}}$, and at low frequencies R^2 is much greater than p^2L^2, and so $C = \frac{E}{R}$. From the no-load curve we find the voltage

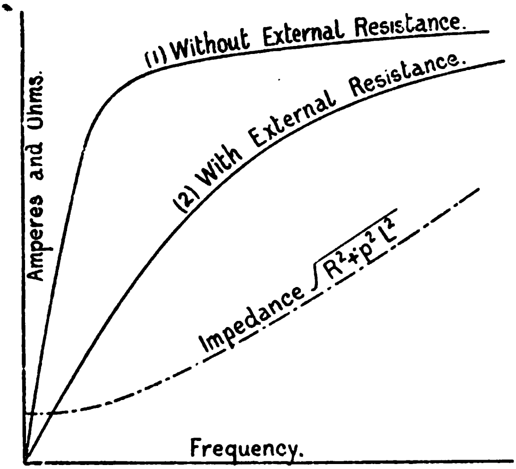


FIG. 9.

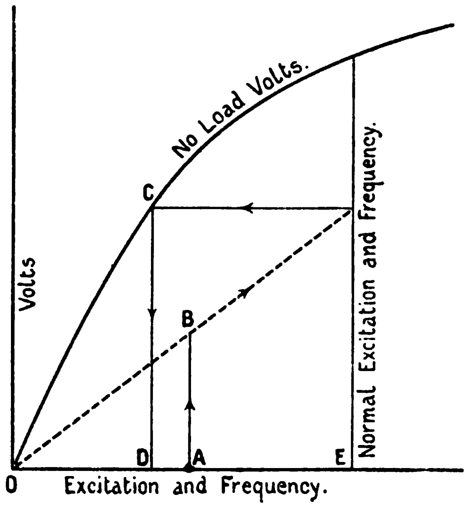


FIG. 10.

E which is being generated (for the current is of unity power-factor), and we can therefore estimate R, which of course is not the simple resistance of the armature, but includes the equivalent resistance due to eddy currents set up by the armature current in the pole-pieces.

At higher frequencies the term p^2L^2 becomes of greater importance and the whole expression $\sqrt{R^2 + p^2L^2}$ appreciably increases. Also the power-factor of the current goes down, and therefore the curve bends over for the two reasons that a smaller E.M.F is generated, and a higher impedance has to be overcome.

The lag of the current at different frequencies may be obtained from the equation $\tan \phi = \frac{pL}{R}$ by substituting the corresponding values of $\tan \phi$ and L (see p. 1146) and thus finding p. Knowing also C, R, p and L, the E.M.F. which is generated may be calculated, and then knowing this, by the construction shown in Fig. 10, the demagnetisation which actually takes place with the known current at the known power-factor may be determined.

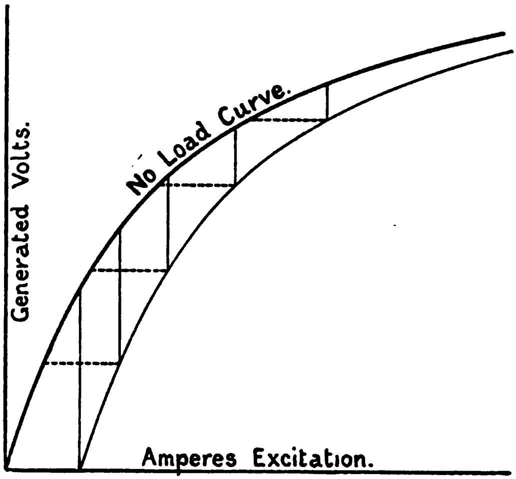


FIG. 11.

If the curve connecting short-circuit current and frequency begins very steeply, a curve better suited for the purpose of this calculation may be obtained by introducing a small resistance into each phase, when a curve more like the second one shown is obtained.

THE COMPARATIVE REGULATING PROPERTIES OF VARIOUS TYPES OF MACHINES.

(1) In Fig. 11, the thick curve is the saturation curve and the thinner one is the same curve shifted a constant distance to the right to allow for a constant demagnetisation. It will be noticed that on the saturated parts of the curve the voltage drop is smallest. As the drop is numerically smaller at higher voltages, the *percentage* drop will be still smaller than at points lower down the curve.

(2) In Fig. 12, the second curve has been drawn out for a constant

voltage drop at zero power-factor, and here it will be seen that for the high parts of the curve much more extra exciting current is needed, although in this case the *percentage* increase appears to be constant up to points well over the bend of the curve. Except only for the lower portions of the curve, these remarks apply for other power-factors.

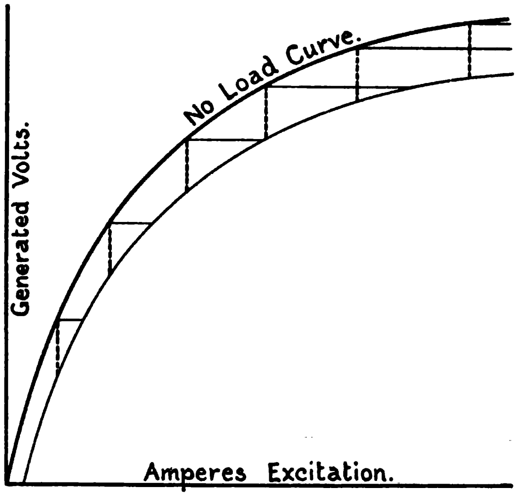


FIG. 12.

(3) In order to minimise the self-induction of the armature, some makers have a rule of making machines with long air-gaps, while others attain the same object with shorter air-gaps by saturating the poles. That is, they work their machines at different parts of the saturation curve, and the relative advantages of either method can be seen from what has been said above. It would be advantageous, however, from the point of view of a minimum excitation to have both a short gap and unsaturated poles. These would be permissible if the poles were made of laminations (as shown in Fig. 13) *parallel* to the shaft, for the local armature lines would find a large reluctance across the pole, just as if it were highly saturated.

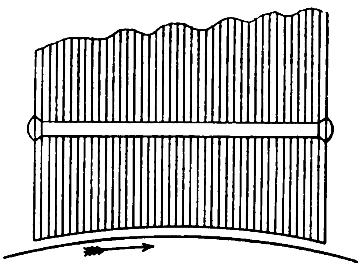


FIG. 13.

(4) *Regulation in machines of different frequencies.*—If in an alternator the peripheral speed and frequency are prescribed, then it follows from the simple rule connecting revolutions per minute, frequency, and number of poles that the pole-pitch is inversely proportional to the

frequency. As examples, Figs. 14 and 15 show the poles of two similar machines designed for different frequencies. It did not, of course, occur that the peripheral speeds were exactly the same, but it will be seen that the pole-pitch of the 50-cycle machine is somewhat of the order of half that of the 25-cycle machine. In two such machines the no-load saturation curves will be about the same, because, although twice the flux is necessary to generate the same voltage in the lower frequency machine, twice the section is provided in the magnetic circuit. Then considering the reactions, there will be twice as many demagnetising ampere-turns in the low-frequency machine as in the other, because there are twice as many conductors under one pole; but, taking the self-induction the same for machines of the same diameter (*i.e.*, running at the same number of revolutions per minute) the reactance voltage drops will be as the frequencies. Then considering the regulation, at unity power-factor, *i.e.*, when there is no demagnetising, the low-frequency machine has less drop; while at zero power-factor it will be seen, from a study of Figs. 11 and 12,

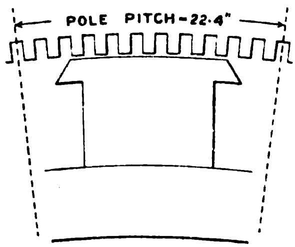


FIG. 14.

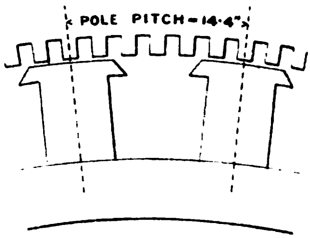


FIG. 15.

there is one excitation at which the two machines regulate equally well, and above this point the low-frequency machine is the better, and below it is the worse. It may be remarked from this that the regulation on zero power-factor is not always a good indication of the general regulating properties of the machine at more usual power-factors.

(5) *Regulation on very high-speed machines such as turbo-alternators.*— In machines making a large number of revolutions per minute, the armature is necessarily much smaller than in more slowly running ones. In these machines the peripheral speed is made as high as possible because there is a limit to the span between the bearings, and as a consequence the self-induction of the armature will be very low, and on high power-factors very small voltage drops will result.

Further, in those types of turbine-driven alternators in which the field winding is carried out as in the stator of an induction motor, the self-induction will be reduced still further, as the armature current cannot distort the flux so much.

Mr. Stoney, of Parsons & Co., has recently said that his firm have obtained full-load pressure drops of only 0·5 per cent. in some of their turbine machines.

NOTES ON THE RUNNING OF SYNCHRONOUS MOTORS.

(1) *Reactions in Synchronous Motors.*—The reactions which occur in synchronous motors are similar to those in generators, but the following points should be noticed.

(*i.*) In generators a lagging current demagnetises, while in a motor it magnetises, and a leading current *vice versa.*

(ii.) In generators the effect of armature reactions is to alter the terminal voltage, but in synchronous the corresponding applied voltage is fixed, and as the excitation is also at any time fixed, the current supplied to the motor so adjusts itself with regard to magnitude and power-factor that the following two conditions are fulfilled : (*a*) the requisite *power* is developed, and (*b*) after the armature current has interacted with the field current, the flux produced is such that the voltage induced by it, compounded with the voltage drop in self-induction, gives the requisite *applied voltage.*

The performance of synchronous motors is generally represented by the V-shaped curves obtained by plotting excitation against current consumption when the power remains constant. Many writers have given constructions depending upon the idea of the "synchronous impedance," but a strictly accurate method would proceed on the lines already indicated in note (*b*) above, the reactions being treated as two distinct effects, as has already been explained in the predetermination of the characteristics of alternators.

In the case of rotary converters where the continuous current is superimposed on the alternating, a further demagnetising takes place as in all continuous-current machines, and a correction may be made for this in the V-curves by shifting each curve as a whole to the right by an amount proportional to the load it represents, but depending also on the lead of the brushes.

(2) *General Remarks on Hunting.*—Hunting may be defined as the periodic variations in speed of synchronous machinery above and below a uniform speed of rotation. Generally, when started, it quickly dies out; but sometimes it sets up influences which cause it to increase, in which case the machine finally breaks out of step.

Surging is spoken of in connection with the variations of current during the hunting. It is an electrical part of the phenomenon of hunting, which, of course, is mechanical.

The following are some of the causes which may start hunting in any part of the circuit :—

(i.) Changes of the total load on the engine, combined with the slow action of its governor.

(ii.) The irregular turning effort of the engine, due to—

(*a*) The irregular crank effort during any one revolution, or
(*b*) What is known as the hunting of the governor started by a change of load, but which may be better described as the periodic dancing of the governor.

(iii.) Changes of load on any synchronous motors, and rotary converters.

Hunting is encouraged :—

(i.) If the natural period of oscillation of any machine on the system corresponds to the period of the hunting resulting from any of the above causes.

(ii.) By the surging current.

Hunting is wiped out by the damping action of the eddy currents which are set up in the pole-pieces, and in special damping devices, such as amortisseurs, by flux changes caused by the hunting.

(3) *Hunting in Synchronous Motors due to Changes of Load.*—In the vector polygon of voltages A D E F in Fig. 5, the angle ϕ is the external angle of lag, *i.e.*, the phase difference between the current and the *terminal* volts; ψ is the phase difference between the current and the internal volts, and θ is the phase difference between the generated volts and the terminal volts. Applying the same voltage polygon to the case of the synchronous motor, A F will be the applied voltage and A D will be the back E.M.F. of the motor, so that ψ will be the phase difference between the current and the applied terminal volts, ϕ will be the phase difference between the current and the back generated voltage of the motor, and θ will again be the phase difference between the terminal voltage and the generated voltage. To consider the meaning of the angle θ in the case of synchronous motors where the motor is small compared with the generator, so that the loading of it will not appreciably alter the voltage of the generator : At no load, the applied volts are in exact phase with the back generated volts, and so the motor will revolve in exact phase with the generator. But as load is put on the motor, there is a lag between the applied voltage and the generated voltage; and so the motor must lag in its rotation a certain angle, θ, behind the position at any instant occupied by the generator. In Fig. 16 some typical curves are given, showing the angle θ for the motor working at different powers. There curves are given for under, normal, and over excitation respectively, and it will be seen that the motor has a higher maximum capacity when over-excited. Suppose the motor is working at any point, such as A, on one of these curves, and then some load is taken off : the power *supplied* to the motor will not change immediately, because it depends only on the angle θ, and this cannot change suddenly. Therefore, as the power supplied is more than required, the motor will accelerate, *i.e.*, the angle θ will diminish. In doing so, the power supplied diminishes, and therefore the excess power also, until the point B, which corresponds to the present load, is reached. But the motor will not remain at this point, because it has accelerated to get there, and is therefore moving at a greater velocity than is necessary for the frequency supplied; and so, acting like a spring, it overshoots the point B and is pulled up because the power supplied is now less than the load.*

* From a study of these curves, two important points may be observed. First, it may be explained why a synchronous motor or rotary converter, when started up as induction motors by the eddy currents induced in the pole-pieces or in the amortisseur, attain a speed of exact synchronism, which induction motors never do. If the induction action is sufficient to bring the machine up to within half a period of exact synchronism, it will act as a synchronous motor, and will travel round a curve such as those in Fig. 16.

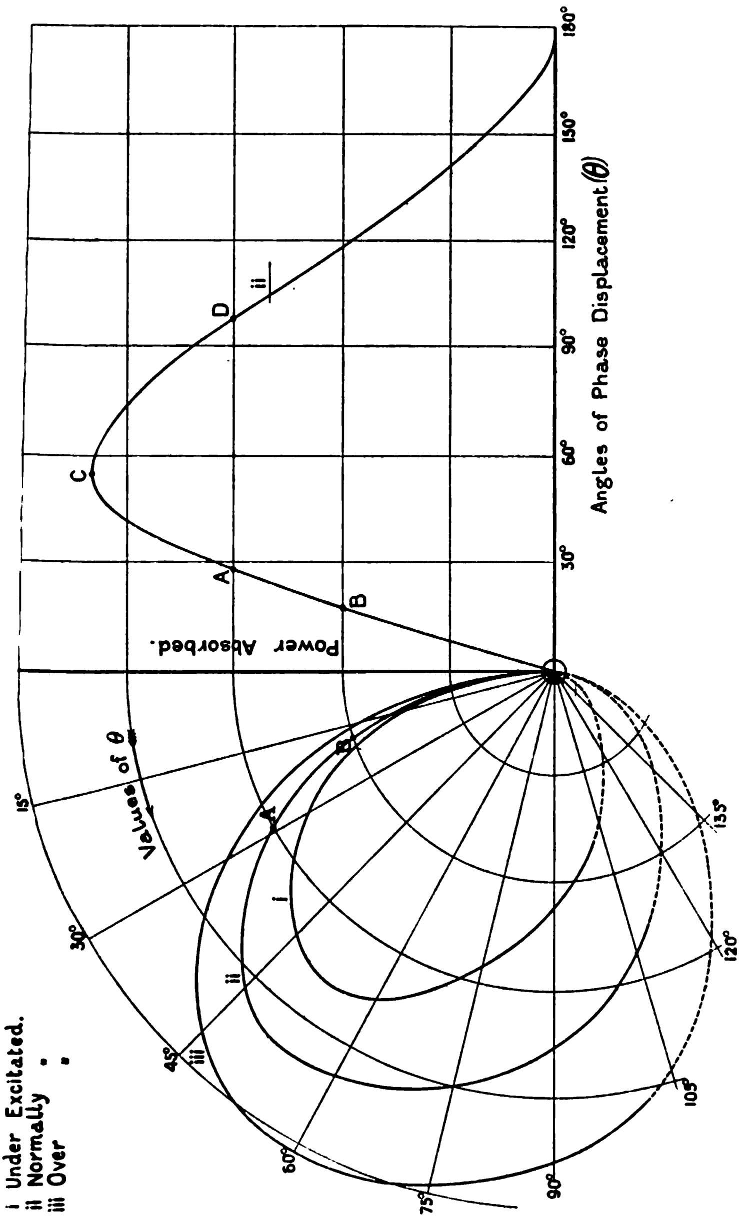

i Under Excitated.
ii Normally "
iii Over "
Power Absorbed.
Angles of Phase Displacement (θ)
Values of θ
A
B
C
D
i
ii
iii
30°
60°
90°
120°
150°
180°
15°
45°
75°
105°
135°

FIG. 16.

If these are the only considerations governing these oscillations, we may express them in the usual way by the equation—

$$\mathrm{I} \cdot \frac{d^2\theta}{dt^2} + f(\theta' - \theta) = 0,$$

where θ is an instantaneous value, and θ' is the value corresponding to the load which is on the machine, and the result is a periodic motion.

There is one important difference between the vibrations of an ordinary spring and the swinging of a synchronous motor, and that is, that whereas in the spring the controlling force is proportional to the displacement, in a motor it is proportionately greater for positions near the no-load than for positions near the maximum load. This is shown better when θ and power are plotted in rectangular co-ordinates. Suppose, for instance, that the load O A has been suddenly put on; the controlling force on the left is fairly proportional to the angle $(\theta - \theta')$; but on the right it is not only not proportional to $(\theta - \theta')$, but it attains a maximum value and then decreases. The motor will therefore swing to the right more than to the left, and if O A is large enough, it will swing past the maximum output position C. If it swings past the position D where the output is the same as at A, it will pull up, because it is moving more slowly than at synchronous speed, and the input is smaller than the output.

This is the second, and perhaps the more usual, way in which motors break out of step.

(4) *The Action of the Surging Current.*—There is still to be considered a term in the general equation which depends upon the velocity. This consists of two parts, viz., a positive part, which is a damping term introduced by the eddy currents in the pole-pieces, etc., and a negative part which results from the action of the surging currents. To deal with the latter first: consider the motor when the load has just been taken off. The voltages exactly balance one another, but when the motor accelerates, the frequency of the voltage generated in the motor is increasing, so that at any instant it cannot be exactly equal and opposite to the voltage which it has to oppose. This action is shown in Fig. 17, where the unbalanced voltage curve is shown underneath the curves for the constant frequency applied volts, and the changing frequency generated volts. When the motor is swinging forward, this curve leads in front of the applied volts, and as the resulting surging current sent through the machine lags 90° (the impedance consist-

corresponding to no-excitation, and will settle down in the position of synchronism.

Secondly, in synchronising alternate-current machinery, it is usual to switch in when the voltage of the incoming machine is exactly in phase with the outside voltage. From what has been said above, it will be seen that only in the case of no load on the machine to be paralleled with is a true phase thus obtained, and in other cases hunting will result. In the case of generators, this may be more or less avoided by a more or less judicious choosing of the phase; in the case of motors, however, hunting must result from a changing of load on one machine when another is put on to work with it, but as it is an advantage to have the machines hunting in the same direction, if motor I. is working at A, motor II. should be switched in when the angle θ between its terminal voltage and the line voltage is that corresponding to the point A.

ing mostly of reactance), it will be nearly in phase with the applied voltage and will therefore produce a torque in the motor, and thus help it in its forward swing. In the back swing, the unbalanced volts lag behind the applied volts, and the surging current, lagging another quarter of a period, •will be opposed to the applied volts, and will therefore produce a negative tongue on the motor, whose backward swing will thus be greater than the previous forward swing. In order that the motor may not thereby break out of step, the damping coefficient, being of opposite sign to the surging coefficient, must have at least the same numerical value.

(5) *The Action of the Amortisseur.*—The amortisseur acts like a very bad induction motor, with the important difference that whereas in the motor about the same flux is always used because the same applied volts must always be choked back, in the armature and the amortisseur the exciting current depends upon the load and produces whatever flux it is able. Currents are induced in the amortisseur (1) by changes in *value* of the flux per pole, and (2) by changes in the *distribution* of the flux in the gap. The currents induced by (1) have no damping action, but they cause the self-induction of the armature to be smaller if the amortisseur rods are not well embedded in the pole-face. This will allow the surging current to be larger. The currents induced by (2) produce damping, and produce more or less with the same current, according as the current in the rods is at unity or zero power-factor, the action being exactly the same as the starting of an induction motor.

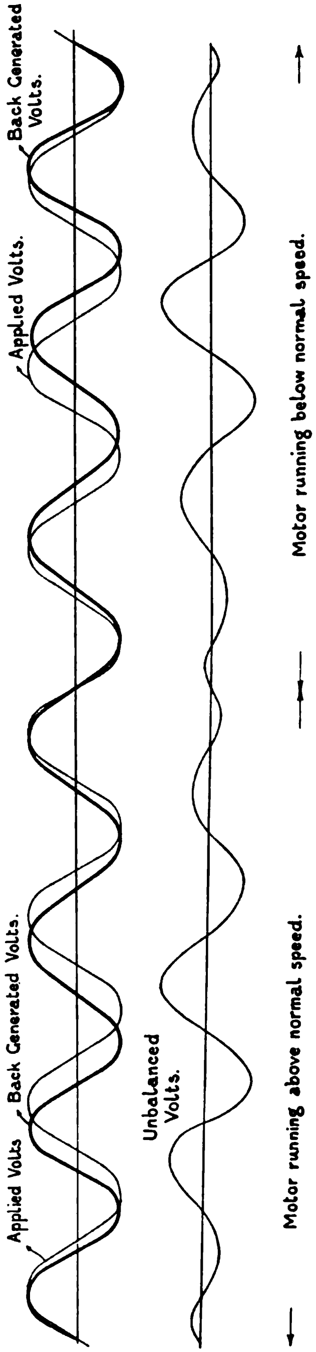


FIG. 17.

The resistance of the amortisseur should therefore be so adjusted that the effects produced by (1) do not counterbalance the damping actions produced by (2).

The *changes* in the flux distribution referred to above are produced in two ways, viz., (1) By the action of the rotating M.M.F.'s (see p. 1144) during any one complete cycle, and (2) by the hunting of the machine.

It is only in the latter case that the amortisseur is required to have any action, and its self-induction should therefore be so arranged that at the frequency at which the first action is produced, *i.e.*, at double or more the alternator frequency, the current is fully inductive, while at the surging frequency, which is of the order of one per second, the amortisseur current is non-inductive, and therefore produces maximum effect.

(6) As this paper is already long, mention only can be made of two extra points in the hunting of synchronous motor-generators and rotary converters.

First, when a number of sets supply continuous current to the same network, the unequal sharing of the load when the sets hunt among themselves must be considered; and secondly, in rotary converters, where the reactions of a synchronous motor and a continuous-current generator occur in the same machine, the amortisseur will be acted upon, not only by changes in the alternate current supplied, but also by changes in the continuous-current load. During the hunting which will follow the change in load, if the alternate current is leading, the damping will be less, and if lagging, more than in the ordinary synchronous motor under similar conditions.

In conclusion, the author wishes to accord his thanks to Dr. S. P. Thompson for many facilities afforded him in collecting matter for this paper, and to Mr. A. C. Lock for help in experiments connected with it.

ALTERNATING-CURRENT COMMUTATOR MOTORS.

By F. CREEDY, Student.

(*Paper read at a Meeting of the Students' Section, May* 4, 1904.)

As the alternating-current commutator motor has recently been coming to the front very much, I have thought that a description of some of these motors and of their manner of working would be of interest to the members of the Students' Section.

For practical work, two distinct kinds of motor appear to be required, corresponding to the continuous-current series and shunt motors. The one is a constant-speed motor, preferably capable of starting under full load, and suitable for many kinds of factory driving, etc. Where polyphase supply is obtainable, the polyphase induction motor fulfils nearly all these requirements. The single-phase induction motor also does nearly as well when once started, being inferior only in its power-factor. The defect of low power-factor, however, can be got over by compensation, a subject to which I intend to return later. I think it extremely probable that the single-phase induction motor, fitted with a commutator, which is used for starting under full load and for compensation, will be extensively employed in the future. Such a motor would have the great advantage of being capable of being employed on ordinary lighting circuits.

Besides the constant-speed motor, another kind of motor is required for traction and similar work, analogous to the continuous-current series motor, *i.e.*, with a starting torque considerably greater than the full-load running torque, and a readily variable speed. It is only within the last year or so, however, that such a motor has been forthcoming, at least on a commercial scale. Nothing startlingly new has been invented, the old-fashioned alternating series motor being found about as good as any, when deprived of its faults by careful design. This motor is in actual commercial use, I think, on the Baltimore, Ohio, and Annapolis Railway, and has also been developed in Italy by Dr. Finzi.

The General Electric Company of America are developing the repulsion motor, which dates from 1887, and, judging from what they say, appear to be getting good results by careful design. A third motor, perhaps the most promising of the three, which is being used for traction purposes in Germany, is the compensated series motor, a combination of the last two. This motor has recently been reinvented by several different people, but was apparently first described in an United States patent filed in 1888, sixteen years ago. I propose in this paper to give a brief account of these motors, and of some others which are of interest in various ways, and also to discuss the question of the compensation of alternating-current motors for wattless current.

THE SERIES MOTOR.

Since a D.C. series or shunt motor runs the same way whichever way its terminals are connected up, it is obvious that such a motor will run on alternating current.

Now the torque of any electric motor is of course due to the mutual action of the rotor current and the flux interlinked with it.

Since a flux perpendicular to the plane of a coil carrying a current can obviously produce in it no tendency to turn, but merely an attraction or repulsion, the only flux which can produce a torque is the component parallel to the plane of the rotor coil—that is, in a motor having brushes, such as the series motor, perpendicular to the brush-line. If the current and flux are alternating, the mean torque is obviously proportional to the mean product of these quantities, or, in other words, to the product of the one into that component of the other which is in phase with it.

We thus obtain the following very general proposition :—

The torque of any electric motor is proportional to the product of the rotor current into that component of the resultant flux which is at right angles to it in space and in phase with it in time. In the series motor, in which the brushes are set perpendicular to the stator axis, this flux is necessarily in phase with the rotor current, since it is produced by the same current as it flows through the stator. The principal difficulties of this type of motor have been the low power-factor, and, in common with other alternating commutator motors, bad sparking.

This last difficulty is due to the fact that the neutral point, at which no E.M.F. is induced in the short-circuited coil, does not exist. For when the brushes are perpendicular to the stator axis and the E.M.F. due to the rotation of the short-circuited coil in the field is zero, the E.M.F. due to transformer action is a maximum, and when the brushes are parallel to the stator axis and the transformer E.M.F. is zero, the E.M.F. of rotation is a maximum. The commutation difficulty, however, is not nearly so serious as has been supposed, as it can be entirely overcome by suitable design, using few turns per segment, carbon brushes, and high-resistance commutator connections, in order to limit the short-circuit current. The other drawback to the motor has been its low power-factor. In order to raise this we must obviously diminish the reactance of the machine. This reactance consists of two parts, the reactance of the field and that of the armature. That of the armature produces no useful effect, so it is an advantage to entirely eliminate it by making the reluctance in the path of the cross flux as great as possible. For this purpose the field magnet is made with distinct pole-pieces, like a direct-current field magnet, instead of being similar to the stator of an induction motor. If it is necessary to reduce the armature reactance still further, we may put a compensating coil in series with the armature, as in Fig 2, wound in such a way that armature and compensating coil form together a non-inductive circuit. On account of the fact that the armature flux is alternating, this compensating coil need not be actually in series with the armature. It will do

if it be merely closed on itself instead, as in Fig. 3. The reactance of the field cannot be altogether got rid of, as a flux is obviously required to make the motor go. By employing few turns on the field, *i.e.*, a weak field for a given current, and low frequencies, the field reactance

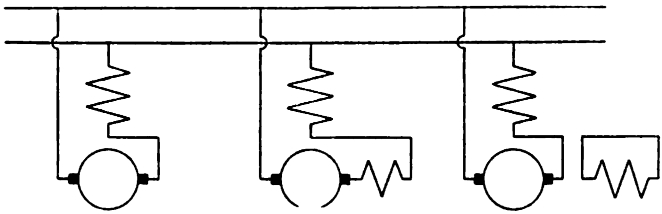


FIG. 1. FIG. 2. FIG. 3.

may be greatly reduced, so that power-factors exceeding 0·9 may be obtained, if the motor be run sufficiently fast. In order to get a good torque with a weak field, a large number of armature turns—as much as four times as many as those on the field—are employed.

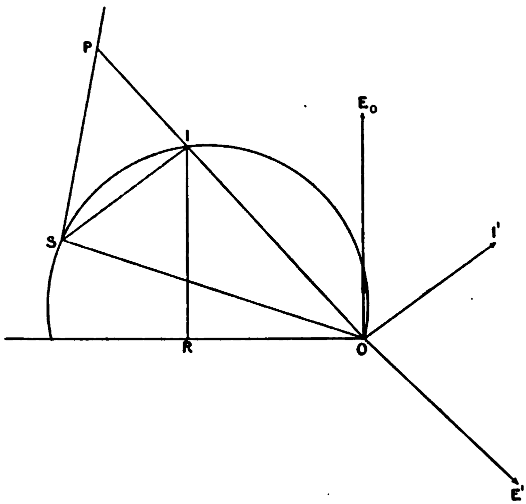


FIG. 4.—Circle-Diagram of the Series Motor.

Current = O I ; speed = $\frac{SI}{OI}$ or S P ; torque = O I^2 ;
output = S I . O I ; efficiency = $\frac{SI \cdot OI}{IR}$.

The series motor, like the induction motor and many others, may be studied by means of the well-known circle-diagram. I give in Fig. 4 a circle-diagram which I have recently worked out for this motor.

In this diagram we see that the current moves on an arc of a circle

which passes through the origin. On account of the iron losses, this circle will have its centre somewhat above the line of zero power-factor.

This diagram may easily be deduced as follows: The motor at standstill is a mere choking coil, and a current O S (see Fig. 4) will flow in it such that the vector sum of all the E.M.F.'s in the circuit, (the impressed E.M.F. and those produced by the current) is zero. Consequently, if another E.M.F., such as the counter E.M.F. produced by the rotation of the armature, be applied to the circuit, it will produce a further current $OI^1 = SI$, lagging behind it by a certain fixed angle. The sum of this current and of the standstill current will be the resultant current, O I. Now, since the counter E.M.F., OE^1, of the motor is exactly in opposition to the resultant current, except for a small but constant angle due to the iron losses, and the current $SI = OI^1$ lags by a constant angle behind it, S I must make a constant angle with O I, the resultant current. Since O S is constant, and $OI = OS + SI$, O I must obviously move on a circle passing through the origin. Moreover, since S I is proportional to the counter E.M.F. of the motor, it must be proportional to the product of speed by flux; or since the flux is proportional to O I,

$$SI \text{ is ppl to } k \times OI, \text{ or } \frac{SI}{OI} \text{ is ppl to } k, \text{ where } k = \text{speed},$$

a construction for the speed which holds for very many types of motor. Since S I is proportional to the counter E.M.F. of the motor, we now see another reason for having many turns on the armature. The more turns we have on the armature of a given motor, the greater will be S I at a given speed. Thus we are enabled to run on that part of the circle at which we get good power-factor, etc., without using excessive speed or a great number of poles.

The speed construction may easily be simplified as follows: Draw a line S P such that the angle O S P equals the angle S I O, and produce O I to meet it in P. The two triangles O S P and S I O will now be similar, since the angle O S P equals the angle S I O, and the angle S O I is common.

Therefore $\frac{PS}{OS} = \frac{SI}{OI}$; and since O S is constant, the speed must be proportional to S P. This is the usual construction for the speed in the induction motor. It holds for the repulsion motor, as was first shown, I think, by Dr. Lehmann, and for many others also. Since the torque is obviously proportional to the square of the current, *i.e.*, to OI^2, we now have the complete diagram shown in Fig. 4. I am in possession of complete experimental confirmation of every part of the above diagram.

In Fig. 5 I have set out along each current vector the output and efficiency corresponding to it, thus obtaining polar curves between these quantities and the angle of lag. The output is obtained from the construction given, viz., output $= SI \cdot OI$, so the shape and position of the curve obviously depends only on the arc intercepted by the vector O S, which represents the standstill current. Since the efficiency depends

only on the output and the ordinate of the extremity of the current vector, which represents the input, we see that these curves have much the same shape for all motors.

The two curves show, in a very graphic way, that the parts of the circle at which the output and the efficiency are high give also a very

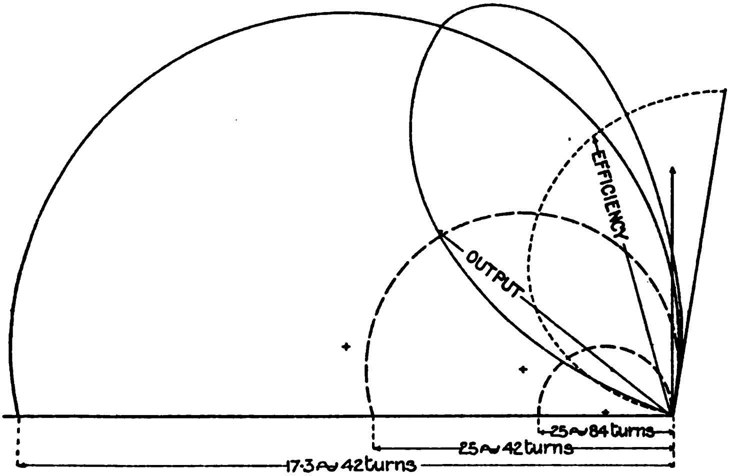


FIG. 5.

good power-factor. It is thus obvious that we should endeavour to work well beyond the top of the circle. To do this we must use a speed which is fairly large, relative to synchronism—that is, if we wish to run at a given speed, we must either use a very low frequency, or a

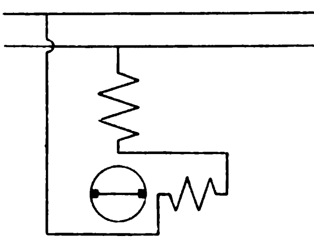


FIG. 6.

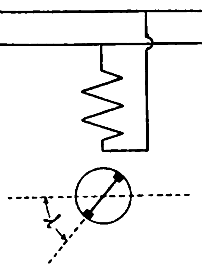


FIG. 7.

large number of poles, or a large number of turns on the armature, or all three, as is done, I believe, by Mr. Lamme. The three current circles I have put in show clearly the effect of altering the frequency keeping the number of field turns constant, and of altering the number of field turns keeping the frequency constant. The diagrams given above are here described for the first time.

The Repulsion Motor.

This motor may be derived from the Series motor in a very ingenious way, due to Mr. Steinmetz. Returning to Figs. 2 and 3, if instead of disconnecting the compensating coil from the mains, and closing it on itself we do the same to the brush circuit, we obtain Fig. 6, a repulsion motor. We may obviously replace the two coils shown by a single coil, making a certain angle with the brush line as in Fig. 7.

Thus the repulsion motor is a transformer motor, like the induction motor. In all transformer motors, two fluxes are required, one to induce the rotor current, and another perpendicular to it to produce the torque. In the repulsion motor we can vary the ratio of these two fluxes with extreme ease, simply by varying the brush position.

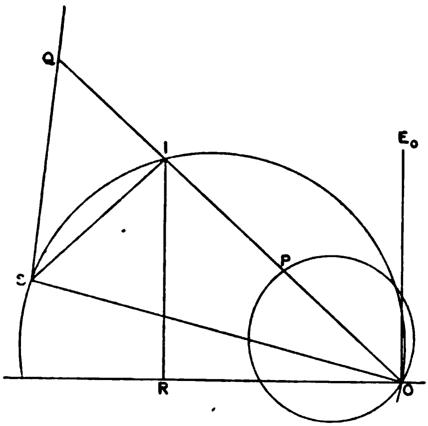


Fig. 8.—Circle-Diagram of the Repulsion Motor.

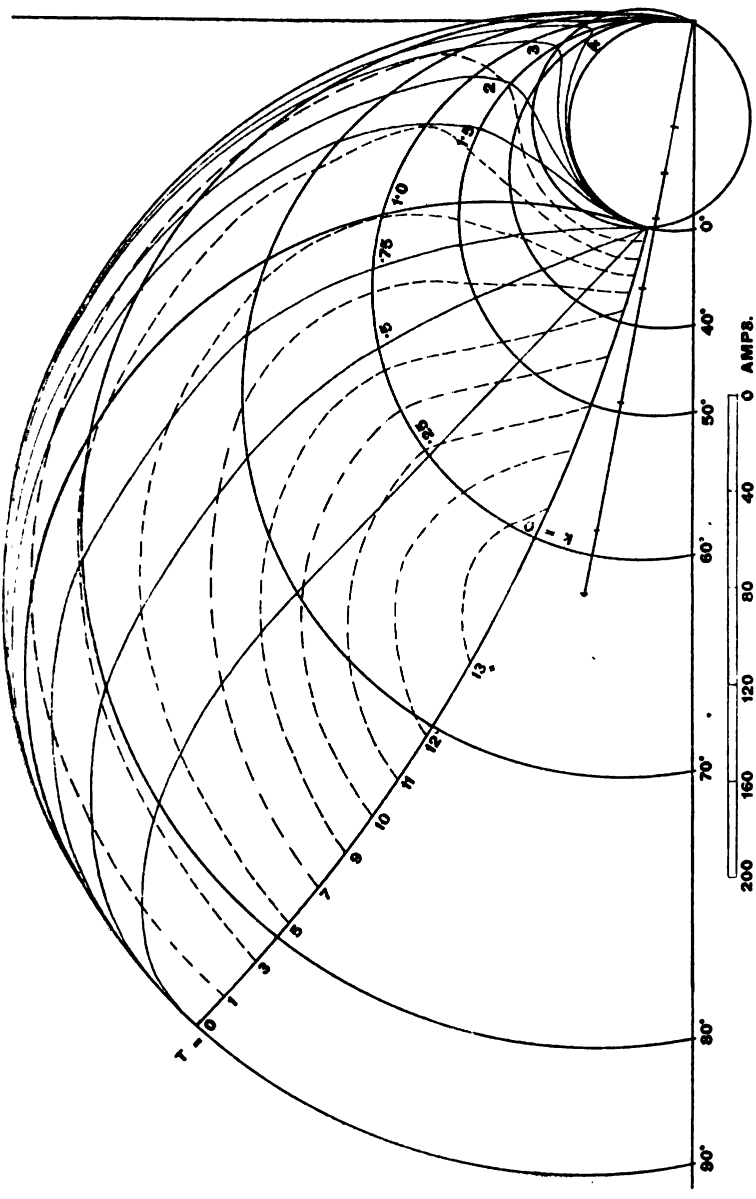
Current = O I ; speed = $\frac{SI}{OI}$ or S Q ; torque = O I . I P ; output = S I . I P ; efficiency = $\frac{SI.IP}{IR}$.

I have recently given a somewhat detailed discussion of the theory of the Repulsion motor in the *Electrical Review.* The Figs. I give here practically contain the essence of it.

The circle-diagram (see Fig. 8) is very similar to that of the series motor, consisting as it does of a circle, having its centre in the same position as that of the series motor, and, like it, passing through the origin. The speed construction is identical with that of the series motor, but, owing to the fact that in the repulsion motor it is possible for the rotor current to get out of phase with the flux, the torque construction is different, the torque being given by O I.I P instead of O I^2, where I P is that part of the current vector which is intercepted between the current circle and another, which I call the torque circle (see Fig. 8). From this diagram we see that the repulsion motor, when unloaded, does not run up indefinitely, but reaches a maximum speed, given by the point of intersection of the torque circle with the current circle. At this point the rotor current is in quadrature with the flux perpendicular to the brush line.

Fig. 9 gives us practically the whole theory of the repulsion motor in a nutshell.

As we move the brushes away from the neutral line in Fig. 7 thus increasing λ, we diminish the field perpendicular to the brush-line



0°
40°
50°
60°
70°
80°
90°
0 AMPS.
40
80
120
160
200
T = 0
1
3
5
7
9
10
11
12
13
1·0
·75
·5
·25
1·5
2
3
4

Fig. 9.

corresponding to that due to coil *b*, the field coil, and increase that parallel to it corresponding to that due to the coil *a* in Fig. 6. In other words, we make the ratio $\frac{\text{armature ampere turns}}{\text{field ampere turns}}$ greater. This was shown to lead to good results in the series motor. As we increase λ the rotor current increases, and with it, of course, the stator current. This is shown in Fig. 9 by the increase in the size of the current circles as λ increases, their centres lying on the straight line shown. If the rotor is held still while we move the brushes the stator current moves on the large circle passing through the origin, which is marked $k = 0$ in Fig. 9.

This circle may easily be determined experimentally as follows :—

Observe—

(i) The "short-circuit current," or the current which flows in the stator, when the brushes are directly under the poles, and its power-factor.

(ii) The "magnetising current," or the stator current when the rotor is open circuited, or when the brushes are perpendicular to the stator axis, and its power-factor.

Set out these two current-vectors, and draw the circle through their extremities and the origin. It is a curious but incontestable fact that the two current-vectors mentioned above completely determine all the electrical features of the motor such as the current, power-factor, etc., for any given speed and value of λ. Two more constants are required to determine the torque, output, etc. A simple construction now enables us to find the point on this circle corresponding to any value of λ, and since the line of centres of the current circles may be proved to be tangent to the standstill current circle at the origin we can now draw in as many current circles as we please.

If the motor is loaded so as always to run at synchronous speed while the brushes are moved, the stator current also moves on a circle. This circle passes through the two points corresponding to the short-circuit and magnetising currents, since when $\lambda = 0$ and $\lambda = 90^\circ$ the stator current is constant and independent of the speed. For the same reason the circle of synchronous speed is tangent to the two extreme current circles. These conditions obviously completely determine it. This circle fixes the scale to which the construction in Fig. 8 measures the speed, and thus enables us to draw in all the other speed-lines which are shown in the figure. The dotted lines in the figure are the lines of constant torque which were plotted from the construction in Fig. 8.*

From the shape of the speed-lines we see that in order to get the best power-factor at any given speed, we must use a somewhat large value of λ, which value gets less as the speed increases. Unless we are prepared to run at two or three times synchronism, however, a value exceeding 60° must be employed. In fact, for the motor shown,

* The figures written against these dotted lines, viz., $T = 0, 1, 3, 5$, etc., give us the torque in synchr. K.W. to which they correspond, *i.e.*, the output in K.W. which the motor would give if, with the same torque, it ran at synchronous speed.

I should be inclined to use about 70°. I believe Mr. Steinmetz uses about 74°. We also see from the torque lines that the standstill torque is not a maximum for $\lambda = 45°$ as has been supposed, but for a value greater than than this (in the motor shown about 63°). For proofs of the above, I must refer to the *Electrical Review* for February 5th and 19th, and March 4, 1904.

Figure 8 shows that we must run at a high-speed relative to synchronism in order to get a good power-factor. Thus the methods employed to get a good power-factor here are very similar to those used in the series motor.

Many other interesting deductions may be made from this diagram, but I have not space to go into them now. It is, indeed, unnecessary, as most of them are sufficiently obvious.

One other point, however, I must mention. The repulsion motor is a rotating field motor, for the flux in the direction of the stator axis being due to the resultant of two nearly opposite currents, is nearly in quadrature with them both. But the flux perpendicular to the stator axis, being due to the rotor current alone, is nearly in phase with it, and thus nearly in quadrature with the first-mentioned flux. Thus the rotating flux is set up. In the neighbourhood of synchronism the coil which is short-circuited under the brush, is moving with the flux and does not cut it. Thus no E.M.F. is set up, and we see that the repulsion motor has less tendency to spark than the series motor, in the neighbourhood of synchronism.

The Shunt Motor.

The alternating-current shunt motor is not of much practical importance, but its theory is extremely simple and interesting, and it is an old friend, so I may as well give some account of it.

At starting, both armature and field current lag considerably, and thus the armature current and flux are approximately in phase, so that the machine starts with good torque.

When running the E.M.F. of rotation produced by the flux tends to bring the armature current into phase with the impressed E.M.F.—that is, out of phase with the flux. Thus the torque rapidly falls off.

The theory of this motor is so simple, that it can easily be deduced geometrically in a few lines. Starting with the impressed E.M.F. E_0 (see Fig. 10), we obtain in the field the current I_0 lagging nearly 90°, Lagging behind this by a small angle, due to the iron losses, we have O E″ the E.M.F. consumed by the E.M.F. of rotation, proportional to the speed k. The resultant of this and the E.M.F. consumed by armature impedance E′ must be the impressed E.M.F. Since the line $E_0E' =$ O E″, and O E″ has a fixed direction and is proportional to the speed, O E′ must move on a straight line parallel to O E″ as we vary the speed. Lagging by a constant angle θ behind O E′ and proportional to it, we have the armature current I_1, which must obviously also move in the same way on a straight line, making the same angle θ with O E″ that O I_1 does with O E′.

Adding the field current $O I_0$ we get $O I$, which also moves on a straight line, parallel to the line on which $O I_1$ moves. When the speed is zero we get the standstill current $O I_\infty$.

The construction for obtaining the speed from the diagram is now obvious. The speed is proportional to the distance between the current vector and the extremity of $O I_\infty$ (see Fig. 10).

The torque is simply proportional to that component of the armature current which is in phase with the flux, since in this motor the flux is constant. The armature current is $I I_0$ in the Fig. The E.M.F. of rotation $O E''$ is in phase with the flux, so that the torque is proportional to the projection of $I I_0$ on $O E''$.

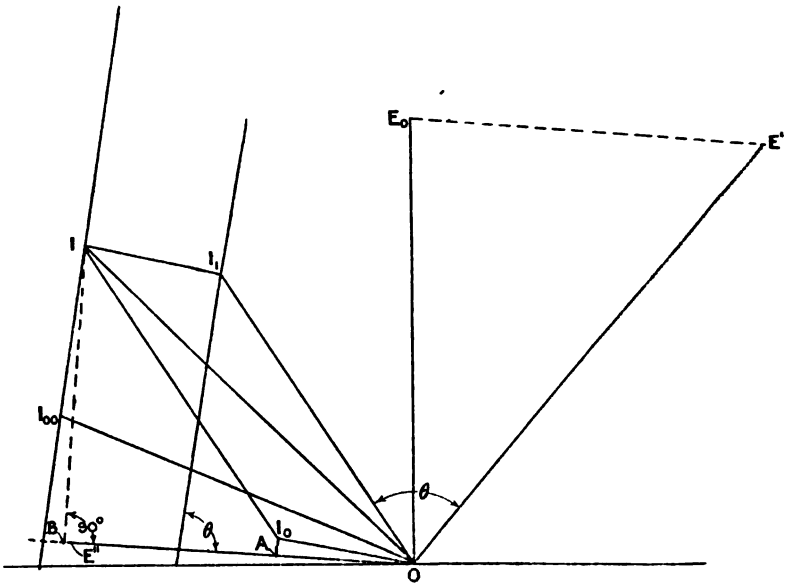


FIG. 10.—Performance Diagram of the Shunt Motor.

$O I$ = current, $I I_\infty$ = speed, $A B$ = torque.

Thus, having constructions for the current, power-factor, speed, and torque, we have all we want to enable us to draw the curves of this motor. This diagram corresponds to the circle diagram of the series and repulsion motors I showed before. It is here described for the first time.

COMPENSATION.

In the next motor I wish to consider, the wattless currents are so compensated that the machine has a power-factor of unity. I think that before discussing it I had better say a few words about compensation in general.

The subject is an extensive one, and might well fill another paper.

It may be looked at from several points of view, but to my mind the clearest and most general is the following :—

Consider a direct-current armature placed inside a ring of laminated iron which completes the magnetic circuit. Suppose four brushes *a, b, c, d* to rest on the commutator 90° apart.

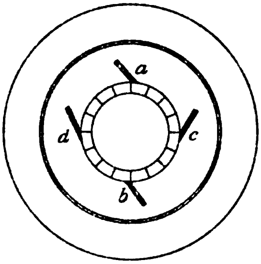


FIG. 11.

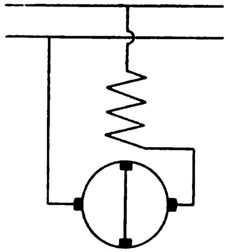


FIG. 12.

Let a current $I_1 = I \sin pt$ flow in the circuit through the brushes *a, b*, and a current $I_2 = I \cos pt$ flow in the circuit through the brushes *c, d*. The current I_1 produces the flux $\phi \sin pt$ in phase with it, and the current I_2 produces the flux $\phi \cos pt$.

Let us consider the E.M.F.'s in the circuit through *a* and *b*.

We have :—

(1) The E.M.F. of self-induction proportional to $-\frac{d\phi}{dt}$.

$$e_1 = -\phi p \cos pt.$$

(2) If the armature is rotating with angular speed $p_1 = kp$ we have the E.M.F. due to rotation in the field $\phi \cos pt$, in phase with it, and proportional to the angular speed.

$$e_2 = k\phi p \cos pt.$$

Thus the resultant E.M.F. is—

$$e_1 + e_2 = k\phi p \cos pt - \phi p \cos pt = (k - 1)\phi p \cos pt.$$

At synchronism when $k = 1$ this vanishes, the E.M.F. of self-induction, lagging 90° behind the current, being exactly balanced by the leading E.M.F. due to the rotation of the armature in the field due to I_2.

Thus the compensation of alternating-current machinery may be looked on as the balancing of the lagging E.M.F.'s of self-induction by an E.M.F. produced by rotation in a field which differs in phase by 90° from the current in the circuit to be compensated.*

The above investigation does not pretend to be at all rigorous. It is only intended to give the leading idea of the subject, so I must ask indulgence for its defects.

* Whether the E.M.F. of rotation shall lead or lag on the current in the circuit to be compensated obviously depends on the direction of rotation.

We may also regard the subject in another light by making use of the conception of the rotating field.

The currents through the brushes set up a rotating field, so that at synchronism no E.M.F. of any kind is induced in the armature, and the currents through the brushes simply flow in a non-inductive circuit.

We are now in a position to consider another motor which is being used for traction purposes in Germany.

The Compensated Series Motor.

This machine is constructed as shown in Fig. 12, and consists of a single-phase stator made like that of an induction-motor with a con-

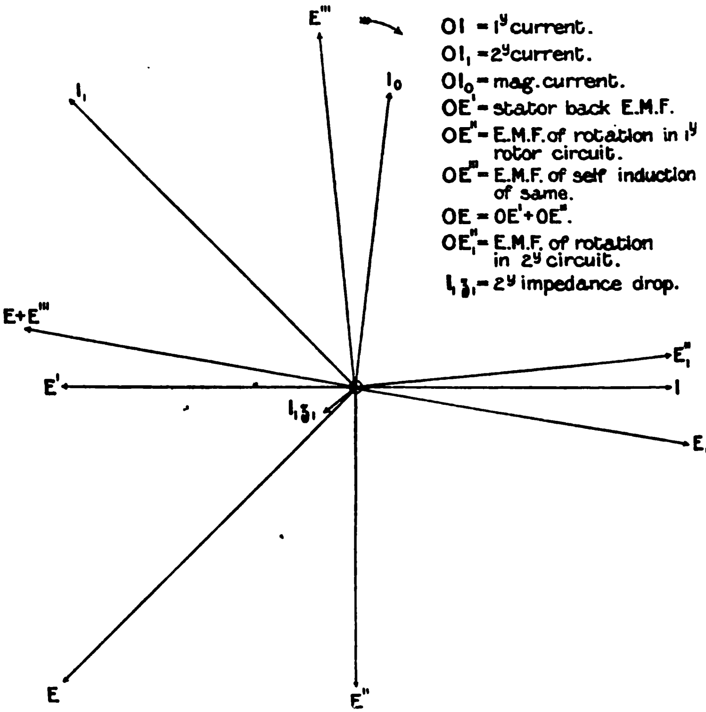


Fig. 13.

stant air-gap all round. In this stator is fitted a direct-current armature, having a pair of brushes perpendicular to the stator axis, just as in a D.C. machine, which are connected in series with the stator winding, either directly or by means of a series transformer. Another pair of brushes is fitted parallel to the stator axis and short-circuited.

The manner in which this motor acts is as follows :—

The current in the stator and in the short-circuited secondary circuit being nearly in opposition, their resultant, the magnetising current, and consequently the resultant flux, will lag nearly 90° behind the stator current.

As it flows through the series armature circuit, the stator current sets up a field in phase with itself, and consequently leading nearly 90° on the flux in the direction of the stator axis. Thus a rotating field is set up and the motor turns.

From another point of view this motor, as regards its torque, is identical with the repulsion motor shown in Fig. 6, the current flowing through the series brushes producing the same flux as that in the coil perpendicular to the brush-line. The object of producing this flux by means of a current in the armature, instead of in an independent coil, is to allow the leading E.M.F. of rotation produced by the resultant flux in the direction of the stator axis to compensate the lagging E.M.F.'s of self-induction in the primary circuit. The E.M.F. of rotation is leading as the motor turns *with* the rotating field, not against it.

Figure 13 gives a phase-diagram. This shows the leading E.M.F. of rotation O E'' very clearly, and also shows how near the power-factor of the motor is to unity at synchronous speed.

The theory of this motor is much more difficult than that of most others, as it is an exception to the very general rule that the current vector moves on a circle as we vary the speed. In this motor it moves on a quartic curve.

No. of Certificate 18,393. **N.L. 17,801.**

THE COMPANIES ACT, 1862 TO 1900.

[COPY.]

SPECIAL RESOLUTION

(Pursuant to the Companies Act, 1862, Sections 50 and 51)

OF

The Institution of Electrical Engineers.

Passed May 19th, 1904, *Confirmed June 9th,* 1904.

AT a Special General Meeting of the Members and Associate Members only of the above-named Institution, duly convened and held in the rooms of the Society of Arts, John Street, Adelphi, W.C., on the nineteenth day of May, 1904, the following Special Resolution was duly passed; and at a subsequent Special General Meeting of the Members and Associate Members only of the said Institution, also duly convened and held in the rooms of the Institution, 92, Victoria Street, in the City of Westminster, on the ninth day of June, 1904, the said Special Resolution was duly confirmed :—

RESOLUTION.

That the Regulations contained in the Articles of Association of the Institution be altered as follows, that is to say :—

1. ARTICLE 39. By adding to the existing Article, after the word "President" in the first line, the words "President Elect."
2. ARTICLE 41. By adding to the existing Article, after the word "President" in the first line, the words "the President Elect."
3. ARTICLE 42. By adding to the existing Article, after the word "re-election" in the seventh line, the following :—

   "The member elected President shall upon election become or, as the case may be, continue a member of Council and be styled 'the President Elect,' but shall not assume office as President until the first Ordinary General Meeting of the Session ensuing next after his election. The President in office at the time of election of a President Elect shall continue in office until the President Elect shall assume office under the foregoing provision. The other elected members of Council shall assume office immediately upon election."
4. ARTICLE 45. By omitting from the existing Article, in the third and fourth lines, the words "for the ensuing year."
5. ARTICLE 49. By adding to the existing Article, after the word "President" in the seventh line, the words "President Elect."

G. C. LLOYD,
Secretary.

The Thirty-Second Annual General Meeting of the Institution was held at the Offices of the Institution 92, Victoria Street, S.W., on Thursday, June 9, 1904, at 5.15 p.m.—Mr. ROBERT KAYE GRAY, President, in the chair.

The Secretary read the notice convening the Meeting.

The minutes of the Ordinary General Meeting of May 26th were read, confirmed, and signed.

The list of names of candidates for election was read, and the President announced that, the Meeting being the last General Meeting of the Session, the ballot would, in accordance with Article 19, be proceeded with that afternoon.

The following list of transfers* was published as having been approved by the Council:—

From the class of Associate Members to that of Members—

William Duddell. | G. McAlpine.
H. St. Hill Mawdsley.

From the class of Associates to that of Associate Members—

Hugh John Holder. | Richard Lloyd Pearson.

From the class of Students to that of Associates—

Alfred Smyth.

Messrs. L. Gaster and J. S. Highfield were appointed scrutineers of the ballot for new members.

Donations to the *Building Fund* were announced as having been received since the last meeting from Messrs. A. P. Patey and E. R. Rudge, to whom the thanks of the Meeting were unanimously accorded.

The PRESIDENT then proposed that the Annual Report of Council be taken as read, and received and adopted.

Mr R. HAMMOND, Hon. Treasurer, seconded the proposal, which was then unanimously carried.

* The following transfers should be added to the list printed on page 472:—

From the class of Students to that of Associates—

Hubert B. Shepheard. Rupert H. Waite. Jas. Percy Winn.

The Institution of Electrical Engineers.

REPORT OF THE COUNCIL PRESENTED AT THE ANNUAL GENERAL MEETING OF JUNE 9, 1904.

The Council have the pleasure of laying before the Annual General meeting their report of the work done during the Session which terminates to-day, the 9th of June, 1904. They are glad to state that the Institution continues to grow both in numbers and in importance, while the Council have endeavoured, they believe not unsuccessfully, to keep the Institution in the forefront of the rapid advances daily occurring in electrical development.

THE ARTICLES OF ASSOCIATION.

The amendments incorporated in the Articles of Association some fifteen months ago, which were referred to in the last Annual Report, have been found during the past Session to be improvements which have facilitated the Institution's development. Experience has taught your Council and the members of the Elections and Transfers Committee that greater definition is necessary in the statement of the qualifications to be required in candidates for admission to the class of Associates of the Institution. Your Council have the matter, one of considerable difficulty, under consideration, and it is hoped that at an early date some reasonable solution of the problem will be found.

A modification of the past practice as regards the period of office of your President has also been under consideration, and the Council have decided to recommend for your acceptance that your President should be elected at the same time as the Vice-Presidents and other members of Council, but that the President should not assume office until the first Ordinary General Meeting of the new Session. During the period between his election and his assumption of office he should be President-Elect and *ipso facto* member of Council. The principal advantage of this arrangement, the Council believe, will be that during the summer recess the business of the Institution will be carried on by the President in concert with his successor, the President-Elect, thus ensuring a continuity of policy.

Resolutions to carry out this change were submitted to a Special General Meeting on the 19th of May, 1904, and will be brought forward

for confirmation at a Special General Meeting, to take place immediately before the Annual General Meeting of the 9th of June, at which this Report will be laid before the Members.

Local Sections.

No new Local Sections have been created during the Session under report, but an increasing amount of valuable work is being done in those previously established, and many of the papers read have been of a high order of excellence.

The Annual Dinners of the several Local Sections, at which Members of Council were present, were reported as very successful gatherings.

Through the initiative of Mr. E. W. Cowan, Chairman, and the other members of the Management Committee of the Manchester Local Section, a Students' Division, numbering already 250, has been formed in that district. The Manchester Section is greatly to be congratulated on the success attending their efforts to provide facilities for the youngest branch of the Institution, and Local Sections may be sure that the Council will assist them so far as it lies in their power.

Congratulations and Thanks.

In view of the hospitality shown to members of the Institution during the visit to Italy in 1903, an illuminated address was prepared for presentation to H.M. the King of Italy on the occasion of His Majesty's visit to this country.

A Deputation consisting of the President, Colonel R. E. Crompton, C.B., Sir Henry Mance, C.I.E., Dr. J. W. Swan, and Professor S. P. Thompson, accompanied by Mr. W. G. McMillan, the Secretary, attended at Windsor Castle, and were graciously received.

A letter of congratulation on the success of the Berlin Zossen-Marienfelde High Speed Railway trials was sent to the "Studiengesellschaft für Elektrische Schnellbahnen."

A letter of congratulation was sent to Lord Kelvin on his election to the Chancellorship of the University of Glasgow.

The Institution is again indebted to the Institution of Civil Engineers and to the Society of Arts for permission to hold Meetings of the Institution in their rooms. The thanks of the Institution are also due to the authorities of the University of Birmingham; of the Royal College of Science, Dublin; of the Institution of Engineers and Shipbuilders, Glasgow; of the Yorkshire College, Leeds; of Owens College, Manchester; and of the Durham College of Science, Newcastle-on-Tyne, for the facilities granted to the Local Sections for the holding of meetings in their rooms.

The Council record their thanks to the owners and managers of the several works, in and around London and in Birmingham, for their kindness to the Students in throwing their factories open to inspection.

Honorary Member.

The Council, in conformity with Articles 11 and 17 of the Articles of Association, have elected as Honorary Member of the Institution, Major-General Charles Edmund Webber, Companion of the Bath, late of the Royal Engineers, Past-President. General Webber is one of the founders of the Institution, and since the time of its inception he has laboured unremittingly for the advancement of its welfare.

Gilbert Celebration.

On the occasion of the 300th Anniversary of the death of William Gilbert, the father of electrical science, Mr. A. Ackland Hunt's painting of Gilbert, showing his experiments on electricity to Queen Elizabeth and her Court, purchased from funds raised by a Committee appointed for the purpose, was formally presented to the Corporation of Colchester at the Ordinary General Meeting of December 10, 1903. Among those who attended the presentation of the picture were:—The Mayor of Colchester, three ex-Mayors, the Town Clerk, and the Borough Electrical Engineer, the Mayor of Westminster, the President of the Royal Society, the President of the Société Internationale des Electriciens, the Senior Censor and Treasurer of the Royal College of Physicians, Dr. Larmor of St. John's College, Cambridge, Mr. A. Ackland Hunt, with Mr. Conrad Cooke and Dr. S. P. Thompson, Joint Honorary Secretaries of the Committee, and Mr. R. Hammond, Honorary Treasurer of the Fund.

Education.

The President has been nominated to serve on a Committee of Engineering Societies convened by the Institution of Civil Engineers, for the purpose of considering questions relating to the education of engineers; and the Council have appointed an Advisory Committee for dealing with the subject.

The President and General Webber were appointed as delegates of the Institution at a Conference between a Consultative Committee and representatives of various Scientific and Commercial Institutions, held under the auspices of the Board of Education, to consider the possibility of arranging for a leaving school examination that would be acceptable as a proof of general education by candidates for admission to professional societies.

The Report of Major-General Webber, which was delivered to the Institution as a contribution to the discussion of Dr. R. M. Walmsley's paper, at the Ordinary General Meeting of February 25th, is published in Part 166 of the Journal.

Elections and Transfers.

Since the last Annual General Meeting there have been elected 31 Members, 174 Associate Members, 142 Associates, and 415 Students, making a total of 762. 29 Associate Members, 2 Foreign Members, and 12 Associates have been transferred to the class of Members; 52 Asso-

ciates and 1 Student have been transferred to the class of Associate Members, and 24 Students to the class of Associates.

Deaths and Resignations.

The Council have to record with extreme regret the loss to the Institution by death of 8 *Members*, Sir F. Bramwell, Bart., F.R.S., J. A. Briggs, J. Hookey, J. C. Kidd, Colonel F. Pescetto, R. C. Quin, The Marquis of Salisbury, K.G., T. J. Wilmot; of 6 *Associate Members*, H. J. Allen, W. Lund, E. Thompson, C. A. Wells, J. C. Woodburn, R. O. Wright; and of 9 *Associates*, F. H. Badger, E. R. Dale, D. Davies, W. Jenkins, R. Lowe, W. G. McMillan (Secretary), C. J. Sevier, E. D. Tiddeman, R. Wood.

Ten Members, ten Associate Members, three Foreign Members, thirty-one Associates, and twenty Students have resigned since the date of the last Report.

Papers.

In addition to the President's Inaugural Address, the following papers, read at Ordinary and Extraordinary General Meetings, will be found in Volume 33 of the Journal :—

Date.	Title of Paper.	Name of Author.
1903.		
Nov. 26.	"The Testing of Electric Generators by Air Calorimetry"	R. Threlfall, F.R.S., Member.
Dec. 10.	"The Slow Registration of Rapid Phenomena by Strobographic Methods"	E. Hospitalier, Foreign Member.
,, 17.	"The City and South London Railway: Working Results of the ThreeWire System Applied to Traction, &c."	P. V. McMahon, Member.
1904.		
Jan. 14.	"On the Magnetic Dispersion in Induction Motors and its Influence on the Design of these Machines"	Dr. Hans Behn-Eschenburg.
,, 28.	"The Edison Accumulator for Automobiles"	W. Hibbert, Associate Member.
Feb. 11.	"Transatlantic Engineering Schools and Engineering"	Dr. R. M. Walmsley, Member.
Mar. 10.	"The Rated Speed of Electric Motors as Affecting the Type to be Employed" ..	H. M. Hobart, Member.
,, 10.	"The Railway Electrification Problem and its Probable Cost for England and Wales" ..	F. F. Bennett, Member.
,, 24.	"Direct Reading Measuring Instruments for Switchboard Use"	K. Edgcumbe, Associate-Member, and F. Punga.
April 14.	"A Theoretical Consideration of the Currents Induced in Cable Sheaths and the Losses Occasioned Thereby"	M. B. Field, Member.
,, 28.	"Power Station Design"	C. H. Merz, Member; W. McLellan, Associate Member.
May 12.	"The Steam Turbine as Applied to Electrical Engineering"	Hon. C. A. Parsons, F.R.S., G. Stoney, and C. P. Martin, Members.
,, 26.	"High Speed Electric Railway Experiments on the Marienfelde-Zossen Line"	A. Siemens, Past-President

The following papers, selected from those read at Local Section Meetings, have been (up to the present) accepted for publication :—

BIRMINGHAM LOCAL SECTION.

DATE.	TITLE.	AUTHOR.
1903.		
Dec. 3.	—Chairman's Inaugural Address	J. C. VAUDREY, Member.
1904.		
Jan. 27.	—"Some Uses of the Oscillograph"	Dr. D. K. MORRIS, Associate Member, and J. K. CATTERSON SMITH, Student.
Feb. 17.	—"The Equipment of an Engine Test House"	R. K. MORCOM, Associate Member.
Mar. 16	—"Localisation of Faults on Low-Tension Networks"	W. E. GROVES, Associate Member.
April 20	—"Some Properties of Alternators under Various Conditions of Load"..	A. F. T. ATCHISON, Associate.

DUBLIN LOCAL SECTION.

1903.		
Nov. 12.	—Abstract of Chairman's Address	Professor W. E. THRIFT, Member.
1904.		
Jan. 14.	—"Three-Phase Working with Special Reference to the Dublin System"	W. BREW, Associate Member.
Feb. 11.	—"Steam Turbines"	F. C. PORTE, Associate Member.
April 14.	—"Notes on Solid Rail Joints"	P. S. SHEARDOWN, Associate Member

GLASGOW LOCAL SECTION.

1903.		
Nov. 10.	—Abstract of Chairman's Address	W. A. CHAMEN, Member.
Dec. 8.	—"The Education of an Electrical Engineer" ..	Prof. F. G. BAILY, Member.

LEEDS LOCAL SECTION.

1904.		
Mar. 10.	—"A Description of the Electrical Equipment of an Engine Works and Shipyard, with Notes thereon"	H. O. WRAITH, Associate Member.

MANCHESTER LOCAL SECTION.

1903.		
Nov. 16	—Abstract of Chairman's Address	E. W. COWAN, Member.
Dec. 15	—"Electric Traction with Alternating Currents"	A C. EBORALL, Member.
1904.		
Feb. 2.	—"The Steam Turbine"	W. CHILTON.
Mar. 1.	—"Mersey Railway Multiple Control"	H. L. KIRKER.

NEWCASTLE LOCAL SECTION.

1903.		
Nov 16.	—Chairman's Inaugural Address	G. G. STONEY, Member.
Dec. 14.	—"Experiments on Eddy Currents"	Dr. W. M. THORNTON, Member.
1904.		
Jan. 18.	—"The Distribution of Electricity in Shipyards and Engine Works"	J. A. ANDERSON, Associate Member.

The papers above referred to have been, or will be, printed in the Journal of the Institution, and, in addition, the following Original Communications have been approved for publication :—

"Gas Power"	J. E. Dowson, Associate.
"Eddy Currents in Solid and Laminated Masses"	M. B. Field, Member.

"Science Abstracts."

Since August, 1903, *Science Abstracts* has been dealt with as a publication of the Institution, the Physical Society contributing towards the expenses and being represented on the Committee of Management. The Secretary of the Institution is the Executive Officer of the Committee, and Mr. Louis H. Walter, M.A., has been appointed Editorial Assistant. Mr. Walter commenced his duties on October 1, 1903.

Arrangements for the publication of *Science Abstracts* have been made with Messrs. E. F. and N. Spon, Ltd. In their last Report the Council stated that they believed the reorganisation of the arrangements would result in an improvement of the publication and in a reduction of the expenses so far as the Institution is concerned. The Council confidently believe that the benefit anticipated is being realised, and that *Science Abstracts*, as now produced, is more valuable to the reader than it ever was. They have also the satisfaction of reporting that a reduction of £364 10s. 7d. in the expenditure of the Institution has been realised.

Wiring Rules and Model General Conditions.

The Council have had pleasure in granting to various individuals and bodies permission to reproduce these two publications.

Annual Premiums.

The Council have awarded the following premiums for papers and communications :—

The Institution Premium, value £25,

to Professor R. Threlfall, for his paper "The Testing of Electric Generators by Air Calorimetry" ;

The Paris Electrical Exhibition Premium, value £10,

to Dr. Hans Behn-Eschenburg, for his paper on "The Magnetic Dispersion in Induction Motors, and its Influence on the Design of these Machines" ;

Three Extra Premiums, value £10 each,

one to Mr. A. C. Eborall, Member, for his paper "Electric Traction with Alternating Currents" (Manchester Local Section); one to Mr. M. B. Field, Member, for his paper "A Theoretical Consideration of the Currents Induced in Cable Sheaths, and the Losses Occasioned thereby"; and the other to Messrs. Edgcumbe & Punga, for their paper "Direct-Reading Measuring Instruments for Switchboard Use" ;

TWO EXTRA PREMIUMS, value £5 each,

one to Mr. A. M. TAYLOR, Member, for his paper "Network Tests, and Station Earthing" (Birmingham Local Section); and the other to Mr. W. BREW, Member, for his paper "Three-Phase Working, with Special Reference to the Dublin System" (Dublin Local Section);

An ORIGINAL COMMUNICATION PREMIUM, value £10,

to Mr. J. E. DOWSON, Associate, for his communication "Gas Power."

STUDENTS' PREMIUMS.

The First Students' Premium, value £7, to Mr. H. W. TAYLOR, for his paper on "Armature Reactions in Alternators, with some Notes on the Running of Motors."

The Second Students' Premium, value £5, to Mr. F. CREEDY, for his paper on "Alternating-Current Commutating Motors."

The Third Students' Premium, value £4, to Mr. R. J. KAULA, for his paper "On the Testing of Alternating-Current Machinery."

An Extra Premium, value £4, to Mr. L. A. LEWIS, for his paper "Notes on Commercial and Experimental Testing of Continuous-Current Machinery."

In accordance with precedent, the Council in making the awards of premiums, have not taken into account the papers contributed by present members of Council. Papers other than those of the Students' Section which were not in type by the end of April, 1904, have been reserved for consideration in awarding premiums in 1905; but certain papers which were received too late for consideration in 1903 have been taken in account this year.

WILLANS PREMIUM.

In accordance with the terms of the Willans Memorial Trust, the selection for the third triennial premium, value £25, fell to your Council, who have made the award to Mr. P. V. McMahon, Member of the Institution, for the papers he read in 1899, "Electric Locomotives in Practice and Tractive Resistance in Tunnels, with Notes on Electric Locomotive Design," and in 1903, "The City and South London Railway: Working Results of The Three Wire System Applied to Traction, &c."

SALOMONS SCHOLARSHIP.

The Council has awarded a Salomons Scholarship, value £50, to Mr. A. B. Chalkley, of King's College, London.

DAVID HUGHES SCHOLARSHIP.

The award of the David Hughes Scholarship, value £50, has this year been made to Mr. J. S. Westerdale, of University College, London.

London Students' Section.

Meetings of the London Students' Section have been held during the Session, at which papers have been read and discussed. Visits to the following places were arranged during the Session :—

1903.

Nov. 28.—The County of London and Brush Electric Lighting Company, City-road, N.

Dec. 10.—The Incandescent Electric Lamp Company, Hammersmith, W.

1904.

Jan. 23.—The India-rubber, Gutta-percha, and Telegraph Works, Company, Silvertown, E.

Feb. 6.—The Baker Street and Waterloo Railway Tunnelling Works.

Feb. 13 and Mar. 12.—The Central Telephone Exchange of the General Post Office.

Feb. 20.—The Central Electric Supply Company, Marylebone, W.

Mar. 5.—Messrs. Sir T. I. Thorneycroft & Co., Chiswick, W.

Mar. 11 and 18.—The Board of Trade Laboratory, Whitehall, S.W.

Mar. 19.—The Metropolitan Electric Supply Company, Willesden, N.W.

Apr. 30.—The Western Electric Company, N. Woolwich.

May 5.—The Electrical Power Storage Co., Millwall, E.

May 21.—The Great Northern and City Railway Company.

The President invited the London Students' Section to appoint three delegates to give the views of the Students during the discussion on Dr. Walmsley's paper. Messrs. O. T. Davis, H. B. Symons, and W. J. Williams were nominated, and their remarks will be found on pages 426, 459, and 461 of Vol. 33 of the Journal.

During the Easter holidays a visit was paid to the following works, in the neighbourhood of Birmingham, in an excursion successfully organised by the Students' Committee, of which Mr. A. G. Ellis was Honorary Secretary :—

Messrs. Belliss & Morcom.
The Birmingham City Electricity Works.
The Birmingham Small Arms Co.
Messrs. Chamberlain & Hookham.
The Electric Construction Co.
The General Electric Co.
The Lanchester Engine Co.
The Loraine Surface Contact System.
The Midland Electric Power Co.
The Municipal Technical School.
Messrs. W. & J. Player.
The New University Power-House.
Messrs. Stewart & Lloyd.
Messrs. Willans & Robinson.

Annual Dinner.

The Annual Dinner was given in the Grand Hall of the Hotel Cecil on the 9th of December, 1903, the company present numbering 465 ; as on the last occasion, the time usually occupied by dinners of this class was curtailed, and an early adjournment was made to the adjoining Victoria Hall for conversation. A salient feature of this dinner was the presence among the guests of a large number of prominent Railway Directors and Engineers, and of several of the distinguished men who have taken a great interest in the educational problems of the day.

International Telegraph Conference.

An event of considerable interest to the Institution was the meeting of the International Telegraph Conference in London in the month of June. In order to offer a fitting welcome to the delegates, the President, on the 11th of June, 1903, gave a Concert in the Royal Albert Hall, to which he invited the delegates, their friends, all members of the Institution, and many other persons connected with the profession. The concert was an unqualified success, and the Institution is much indebted to the President for so worthily representing the whole body of Electrical Engineers on this occasion.

Annual Conversazione.

The Annual Conversazione was held on the 23rd of June, 1903, at the Natural History Museum, when the Institution had the privilege of offering a further welcome to the Government Delegates to the International Telegraph Conference, and the representatives of the Telegraph Companies.

Annual Accounts and Financial Position.

The Council have again to congratulate the Institution on its financial position ; the surplus of receipts over expenditure for the year 1903 having amounted to £2,911 7s. 9d., as compared with £950 19s. 9d. in 1902. The increase is due in a great measure to the unification of the rates of subscriptions. It is gratifying to note that, notwithstanding a considerable increase in membership, the total expenditure for the year was only slightly higher than that for the preceding year. The accounts now presented are in the same form as was adopted in those presented a year ago, and a comparison is therefore very easy.

New Offices.

The Council have granted to the Faraday Society permission to hold meetings in the Library of the Institution.

The Council have to thank Mr. J. E. Kingsbury, Vice-President, for the Electric Bells and the Inter-Departmental Telephone which he has kindly installed in the new offices.

Building Site and Building Fund.

The Building Fund, which at the commencement of the year 1903 stood at £10,691 1s. 11d., amounted on the 31st of December to £12,884 0s. 7d. The increase included a sum of £1,650 transferred from the surplus income.

A Special General Meeting of Members, Associate Members, and Associates was held on July 31, 1903, to take powers to sell any securities held by the Institution for the purpose of purchasing a Building Site, and the Council now have pleasure in announcing that a site was acquired on March 25, 1904. This site, which is partly freehold and partly held on a 999 years' lease from the Ecclesiastical Commissioners, has a total area of 5,200 square feet, with a frontage of 61 feet on Tothill Street, Westminster. The Committee has been continually at work on the somewhat tedious negotiations connected with a purchase where many interests are involved, and the Chairman, Major-General Webber, has been indefatigable in carrying the matter to a successful issue. Although your Council did not think it wise to lose a favourable opportunity for acquiring a valuable site, yet they have no intention of recommending that the construction of a building be immediately proceeded with. They wish to avoid financial embarrassments, and the present occasion is not, they think, most opportune for incurring the heavy outlay which the erection of a suitable building will entail. The Council are advised that the property which they have secured is an improving value, and that the rents now received will provide an income about equal to the income derived from the securities which were sold to provide the funds for the purchase.

The Institution Benevolent Fund.

The Council strongly recommend this Fund to the notice of members. It is now administered by the Council, who greatly regret that the number of Annual Contributors, instead of increasing with the growth of the Institution, is steadily diminishing. Regular annual contributions of small amounts would do much to ensure the future usefulness of this fund.

A grant from the income of this Fund to the widow of Mr. W. G. McMillan has been authorised.

Wilde Benevolent Fund.

No grant has been made from this Fund during the year.

Local Honorary Secretaries.

It was with deep regret that the Council received the notification of the death of Colonel F. Pescetto, who, since 1900, had acted as Local Honorary Secretary and Treasurer for Italy. They are fortunate in securing the services of Mr. Guido Semenza as Colonel Pescetto's successor. Mr. A. S. Baxendale has been appointed Local Honorary Secretary and Treasurer for the Straits Settlements and Netherlands Indies, in the place of Mr. W. Grigor Taylor, who resigned last year.

Visit to America.

St. Louis Exhibition Congress.

A communication has been received by the Council from Mr. Bion J. Arnold, President of the American Institute of Electrical Engineers, and from the Council of that Society, inviting the Members of the Institution to take part in the International Electrical Congress which will meet at St. Louis, in the State of Missouri, on the 12th, and will close on the 17th September, 1904. There has also been received an invitation, from our Canadian Members, to visit Montreal on the 7th and 8th of the same month. In view of the popularity and success attending the Foreign Visits in recent years, your Council have decided to undertake the organisation of an American Visit, the cost of which will be paid by the participants. As the Congress to be held at St. Louis is International in character, and as questions affecting the electrical industry will be discussed, your Council have decided to appoint delegates to attend the meetings.

The following American and Canadian gentleman have kindly accepted nomination as Members of the Foreign Visits Committee of the Institution :

Prof. Goldsborough,
Mr. C. A. Hering,
Mr. S. Insull,
Dr. A. E. Kennelly,
Mr. C. O. Mailloux,
Mr. F. Nichols,
Dr. R. B. Owens,
Mr. Calvin W. Rice,
Prof. E. Thomson,
Mr. G. G. Ward.

National Physical Laboratory.

At the invitation of Sir William Huggins, President of the Royal Society and the Board of Management of the National Physical Laboratory, several members of the Institution visited with great interest the Installation at Bushey House, Teddington. They were received by Lord Rayleigh, the Chairman of the Board ; by Dr. R. T. Glazebrook, the Director ; and by the other members of the Staff. The National Physical Laboratory is steadily increasing its sphere of usefulness, and is now able to undertake numerous investigations which are of great utility to Electrical Engineers and others.

Engineering Standards Committee.

The Engineering Standards Committee are still at work, and have appointed various sub-committees, who are engaged in taking evidence and studying the problems before them. On the recommendation of the Institution's Representatives on the Main Committee, the Council has made a further grant of £50 towards the expenses of the Committee.

Work of the Institution.

During the past year there have been 27 Committees at work, 16 General Meetings, 2 Special General Meetings of Members, 27 Council Meetings, and 91 Committee Meetings have been held.

Ronalds Memorial Tablet.

Arrangements have been made by the Council to restore, at the expense of the Institution, the tablet, now in a dilapidated condition, which was erected at Kelmscott House, Upper Mall, Hammersmith, to the memory of the late Sir Francis Ronalds, whose valuable Library is under the care of the Institution.

Death of Mr. W. G. McMillan.

It is with great regret that the Council have to record the serious loss the Institution has sustained through the death, on the 31st of January, of Mr. W. G. McMillan. Mr. McMillan was appointed Secretary on October 1, 1897, and assumed office on February 12, 1898. The sentiments of the Council were well expressed at the Ordinary General Meeting of February 11 by the President, Sir Henry Mance, and Professor Perry.

The Council feel that they can here add nothing more entirely appropriate than that which was then so well and sympathetically expressed in condolence with the bereaved family.

Secretaryship.

The applications received in response to the advertisement inserted in the press for a successor to Mr. McMillan were ninety-five in number, and were carefully considered by a Committee appointed by the Council.

A certain number of the candidates whose qualifications appeared to meet the requirements were personally interviewed by the Committee, and a selected number were subsequently submitted to the Council, who finally appointed Mr. George C. Lloyd, late Chief Assistant to the Secretary of the Iron and Steel Institute. The Council also appointed Mr. P. F. Rowell Assistant Secretary and Accountant, and Mr. R. Tree Chief Clerk.

Mr. Lloyd entered on his duties at the Institution Offices on the 12th May ultimo.

In the interval between the death of the late Secretary and the appointment of Mr. Lloyd, the President devoted a very considerable amount of his time to the affairs of the Institution, and it was largely owing to his unremitting attention that the continuity of the work of management went on without break or interruption.

The Library.

The accessions to the Library during the period from May 28, 1903, to the date of this Annual General Meeting, numbered 108; nearly all of these have been presented by the authors or publishers.

The supply of Specifications of Electrical Patents and of Abridgments of Specifications relating to Electricity and Magnetism is continued by the kindness of H. M. Commissioners of Patents, and the arrangement is still in force whereby the Specifications of all Electrical

Patents published during any week are placed on the Library table on the following Monday morning.

The periodicals or printed Proceedings of other societies received regularly are, with some additions, the same as last year.

The number of visitors to the Library in the twelve months from May 28, 1903, to June 1, 1904, inclusive, has been 359, of whom 34 were non-members.

APPENDIX TO REPORT.

TRANSACTIONS, PROCEEDINGS, &c., RECEIVED BY THE INSTITUTION.

BRITISH.

Asiatic Society of Bengal, Journal and Proceedings.
Cambridge Philosophical Society.
Engineering Association of New South Wales.
Greenwich Magnetical and Meteorological Observations.
Institute of Patent Agents, Transactions.
Institution of Civil Engineers, Proceedings.
Institution of Engineers and Shipbuilders in Scotland.
Institution of Mechanical Engineers, Proceedings.
Iron and Steel Institute, Proceedings.
King's College Calendar.
Liverpool Engineering Society, Proceedings.
Municipal Electrical Association, Proceedings.
National Physical Laboratory Report.
North of England Institute of Mining and Mechanical Engineers, Transactions.
Physical Society, Proceedings.
Royal Dublin Society, Transactions and Proceedings.
Royal Engineers' Institute, Proceedings.
Royal Institution, Proceedings.
Royal Meteorological Society, Proceedings.
Royal Scottish Society of Arts, Transactions.
Royal Society, Proceedings.
Royal United Service Institution, Proceedings.
Society of Arts, Journal.
Society of Chemical Industry, Journal.
Society of Engineers, Proceedings.
Surveyors Institution, Transactions.
University College Calendar.

AMERICAN AND CANADIAN.

American Academy of Science and Arts, Proceedings.
American Institute of Electrical Engineers, Transactions.
American Philosophical Society, Proceedings.
American Society of Mechanical Engineers, Transactions.
Canadian Society of Civil Engineers, Transactions.
Cornell University, Library Bulletin.
Engineers' Club of Philadelphia, Proceedings.
Franklin Institute, Journal.
John Hopkins University, Circulars.
Nova Scotia Institute of Science, Proceedings.
Ordnance Department of the United States, Notes.
Western Society of Engineers, Journal.

BELGIAN.

Association des Ingénieurs Électriciens sortis de l'Institut Electro-Technique Montefiore, Bulletin.
Société Belge d'Électriciens, Bulletin.

DANISH.

Tekniske For ening, Tidsskrift.

DUTCH.

Konin klijk Institut van Ingenieurs, Tijdschrift.

FRENCH.

Académie des Sciences, Comptes Rendus Hebdomadaires des Séances.
Association Amicale des Ingénieurs-Électriciens, B ulletin Mensuel.
Société Française de Physique, Bulletin des Séances.
Société des Ingénieurs Civils, Mémoires.
Société Internationale des Électriciens, Bulletin.
Société Scientifique Industrielle de Marseille, Bulletin.

GERMAN.

Verein Deutscher Ingenieure, Zeitschrift.
Verein zur Beförderung des Gewerbfleisses, Verhandlungen.

ITALIAN.

Associazione Elettrotecnica Italiana, Atti.

RUSSIA.

Section Moscovite de la Société Impériale Technique Russe.

LIST OF PERIODICALS RECEIVED BY THE INSTITUTION.

BRITISH.

Cassier's Magazine.
Electrical Engineer.
Electrical Review.
Electrical Times.
Electrician.
Electricity.
Electro-Chemist and Metallurgist.
Engineer.
Engineering.
Engineering Times.
English Mechanic and World of Science.
Feilden's Magazine.
Illustrated Official Journal, Patents.
Indian and Eastern Engineer.
Invention.
Light Railway and Tramway Journal.
Mechanical Engineer.
Nature.
Page's Magazine.
Philosophical Magazine.
Scottish Electrician.

AMERICAN.

American Electrician.
Electrical Review.
Electrical World and Electrical Engineer.
Electricity.
Engineering News.
Journal of the Telegraph.
Physical Review.
Scientific American.
Street Railway Journal.
Street Railway Review.
Technology Quarterly.
Western Electrician.

AUSTRIAN.

Zeitschrift für Elektrotechnik.

DUTCH.

De Ingenieur.

FRENCH.

Annales Télégraphiques.
L'Eclairage Électrique.
L'Electricien.
L'Industrie Électrique.
Journal de Physique.
Journal Télégraphique.
Le Mois Scientifique et Industriel.

GERMAN.

Annalen der Physik und Chemie.
Beiblätter zu den Annalen der Physik und Chemie.
Centralblatt für Accumulatoren und Elementenkunde.
Electrotechnischer Anzeiger.
Electrotechnische Zeitschrift.
Technische Literatur.
Zeitschrift für Elektrochemie.
Zeitschrift für Instrumentenkunde.

ITALIAN.

L'Elettricità.
Giornale del Genio Civile.
Il Nuovo Cimento.

SPANISH.

La Ingenieria.

STATEMENT OF INCOME AND ... ENDING 31st

Dr.

EXPENDITURE.

		£ s. d.	£ s. d.
To MANAGEMENT:—			
Salaries		1,385 7 1	
Retiring Allowance		300 0 0	
Accountants' Fees		15 15 0	
Addressing of Circulars and Notices... ...		67 9 10	
Printing and Stationery		410 4 6	
Postage		623 10 3	
Telephone		26 10 0	
			2,837 16 8
„ PUBLICATIONS:—			
Journal (Printing and Illustrating)		842 16 1	
"Science Abstracts"—			
Net Disbursements ...	£925 7 5		
Less Subscriptions... ...	369 18 0		
		555 9 5	
			1,398 5 6
„ MEETINGS:—			
Advance Proofs, Refreshments, &c.		173 1 9	
Reporting		56 14 0	
			229 15 9
„ RENT, LIGHTING, AND FIRING			559 10 5
„ INSURANCE			9 15 0
„ DEPRECIATION:—			
Library (5 %)		67 4 11	
Furniture (5 %)		19 11 0	
			86 15 11
„ PREMIUMS			90 14 8
„ CONVERSAZIONE (irrespective of Printing and Postage) ...			286 0 2
„ ANNUAL DINNER			42 6 0
„ ITALIAN VISIT			6 17 3
„ LOCAL SECTIONS			352 10 11
„ GRANT TO ENGINEERING STANDARDS COMMITTEE			250 0 0
„ EXPENSES IN CONNECTION WITH REMOVAL TO NEW PREMISES:—			
Removing Furniture		29 0 0	
Renovation of Furniture		60 17 9	
Electric Light Wiring and Fittings		56 2 6	
Refixing Telephone		4 4 4	
Name Plates		5 9 6	
			155 14 1
„ GENERAL EXPENSES:—			
Address to H.M. The King of Italy... ...		18 10 0	
Building Plans		13 4 0	
Sundries		110 16 11	
			142 10 11
„ BALANCE carried to General Fund, being excess of Income over Expenditure			2,911 7 9
			£9,360 10 6

Electrical Engineers.

EXPENDITURE FOR THE YEAR DECEMBER, 1903.

Cr.

INCOME.

	£	s.	d.	£	s.	d.
BY SUBSCRIPTIONS FOR 1903 :—						
Received	8,056	13	0			
Outstanding (Estimated Value)	500	0	0			
				8,556	13	0
" DIVIDENDS ON INVESTMENTS :—						
Life Compositions	£167	14	1			
General Fund	191	16	5			
				359	10	6
" INTEREST ON CASH ON DEPOSIT				77	6	3
" JOURNAL :—						
Sales (Net Proceeds)	125	6	1			
Advertisements	191	0	0			
				316	6	1
" WIRING RULES				50	14	8
				£9,360	10	6

Dr.

	£	s.	d.
To Amount (as per last Account)	5,381	10	0
„ Life Compositions received during 1903	71	8	0
	£5,452	18	0

Cr.

				£	s.	d.
By Investments (as per last Account) :—						
£400	0	0	New South Wales 4 % Bonds	414	15	0
318	0	0	Cape of Good Hope 4 % Consolidated Stock	306	0	0
1,679	19	5	India 3½ % Stock	1,776	5	0
120	0	0	South-Eastern Railway 5 % Debenture Stock	204	16	6
355	5	10	Canada 3 % Stock	352	13	6
289	17	4	Midland Railway 2½ % Consolidated Perpetual Preference Stock	274	11	10
6	0	0	East Indian Railway Class "C" Annuity ...	185	1	9
87	0	0	Great Eastern Railway 4 % Consolidated Preference Stock	130	15	2
175	0	0	Great Eastern Railway 4 % Debenture Stock	251	5	5
4	13	6	Great Indian Peninsula Railway "B" Annuity	120	1	6
143	0	0	Southwark and Vauxhall Water Co. 4 % A. Debenture Stock	207	17	9
520	0	0	Staines Reservoirs 3 % Guaranteed Debenture Stock	539	2	3
200	0	0	Glasgow and South-Western Railway 4 % Preference Stock (1894)	276	5	0
29	0	0	Madras Railway 5 % Stock	44	9	4
57	0	0	South Indian Railway 4½ % Debenture Stock	84	0	0
30	0	0	Burma Railway Co.'s Stock	30	12	3
40	0	0	East Indian Railway 4½ % Debenture Stock ...	57	3	7
				£5,255	15	10
,, Balance uninvested carried to Balance Sheet				197	2	2
				£5,452	18	0

Dr.

				£	s.	d.
To Amount (as per last Account) :—						
Invested...	£10,147	7	9			
Uninvested	543	14	2			
				10,691	1	11
„ Dividends received during 1903				302	8	0
„ Subscriptions received during 1903				231	11	0
„ Surplus from Vellum Diplomas				8	19	8
„ Amount transferred from General Fund in 1903				1,650	0	0
				£12,884	0	7

FUND.

Cr.

				£	s.	d.
By Investments (as per last Account) :—						
£450	0	0	Canada 4 % Reduced Stock	504	0	0
524	13	0	Canada 3 % Stock	553	10	1
181	0	0	Great Western Railway 4½ % Debenture Stock ...	324	17	8
418	0	0	South-Eastern Railway 3½ % Preference Stock ...	555	18	9
370	0	0	London and South-Western Railway Preferred Ordinary Stock	510	12	0
520	0	0	London and South-Western Railway 4 % Consolidated Preference Stock	821	12	0
190	16	8	India 3½ % Stock	229	9	6
387	0	0	Great Eastern Railway 4 % Consolidated Preference Stock	575	17	8
529	12	0	Midland Railway 2½ % Consolidated Perpetual Preference Stock	500	0	0
23	7	5	Great Indian Peninsula Railway "B" Annuity	600	2	6
80	0	0	London and South-Western Railway 3½ % Preference Stock	99	18	3
504	0	0	Staines Reservoirs 3 % Guaranteed Debenture Stock	528	5	0
670	0	0	Glasgow and South-Western Railway 4 % Preference Stock (1894)	925	11	9
75	0	0	Great Eastern Railway 4 % Debenture Stock	107	13	7
15	0	0	South-Eastern Railway 3 % Preference Stock	15	0	0
220	0	0	Madras Railway 5 % Stock	340	0	5
343	0	0	South Indian Railway 4½ % Debenture Stock ...	509	2	0
320	0	0	South-Eastern Railway Preferred Ordinary Stock	511	1	0
970	0	0	Burma Railway Co.'s Stock	989	12	9
670	0	0	East Indian Railway 4½ % Debenture Stock ...	945	2	10
				£10,147	7	9
Building Site—Deposit on Purchase				1,650	0	0
Balance uninvested carried to Balance Sheet				1,086	12	10
				£12,884	0	7

SALOMONS SCHOLARSHIP

Dr.

	£	s.	d.
To Amount (as per last Account)	2,126	19	3
	£2,126	19	3

SALOMONS SCHOLARSHIP

Dr.

	£	s.	d.
To Amount paid to Scholars in 1903...	75	0	0
„ Balance carried to Balance Sheet	75	9	1
	£150	9	1

DAVID HUGHES SCHOLAR-

Dr.

	£	s.	d.
To Amount (as per last Account)	2,000	0	0
	£2,000	0	0

DAVID HUGHES SCHOLAR-

Dr.

	£	s.	d.
To Amount paid to Scholars in 1903...	50	0	0
„ Balance carried to Balance Sheet	57	2	2
	£107	2	2

WILDE BENEVOLENT

Dr.

	£	s.	d.
To Amount (as per last Account)	1,500	0	0
	£1,500	0	0

WILDE BENEVOLENT

Dr.

	£	s.	d.
To Amount invested in P.O. Savings Bank...	158	9	0
	£158	9	0

FUND CAPITAL.

Cr.

				£	s.	d.
By Investments :—						
£1,500 New South Wales 3½ % Stock ...	£1,556	5	9			
500 Cape of Good Hope 3½ % Stock ...	570	13	6			
				2,126	19	3
				£2,126	19	3

FUND INCOME.

Cr.

	£	s.	d.
By Balance (as per last Account)	80	1	2
„ Dividends received in 1903	70	7	11
	£150	9	1

SHIP FUND CAPITAL.

Cr.

	£	s.	d.
By Investment :—£2,045 Staines Reservoirs 3 % Guaranteed Debenture Stock	1,998	15	0
„ Balance uninvested carried to Balance Sheet	1	5	0
	£2,000	0	0

SHIP FUND INCOME.

Cr.

	£	s.	d.
By Balance (as per last Account)	45	13	6
„ Dividends received in 1903	61	8	8
	£107	2	2

FUND CAPITAL.

Cr.

	£	s.	d.
By Investment :—£875 Great Eastern Railway Metropolitan 5 % Guaranteed Stock	1,493	16	3
„ Amount invested in P.O. Savings Bank	6	3	9
	£1,500	0	0

FUND INCOME.

Cr.

	£	s.	d.
By Amount (as per last Account)	111	7	7
„ Dividends received in 1903	43	16	3
„ Interest do. do.	3	5	2
	£158	9	0

BALANCE SHEET,

Dr.

LIABILITIES.

			£ s. d.
To Sundry Creditors			732 8 1
„ Local Sections :—			
Due to Hon. Sec. Dublin Section			2 1 10
„ Subscriptions received in advance :—			
On Account of 1904		86 9 0	
do. do. 1905, 1906, and 1907 ...		10 0 6	
			96 9 6
„ Salomons Scholarship Fund Income			75 9 1
„ David Hughes Scholarship Fund :—			
Capital uninvested		1 5 0	
Income		57 2 2	
			58 7 2
„ Entrance Fees			1,824 9 0
„ Life Compositions uninvested			197 2 2
„ Building Fund uninvested			1,086 12 10
„ General Fund :—			
As per last Balance Sheet		6,327 2 4	
Add Excess of Income over Expenditure for 1903		2,911 7 9	
Subscriptions for years previous to 1903 received in 1903	556 12 0		
Less Estimated Value at 31st of December, 1902... ...	410 0 0		
		146 12 0	
Subscriptions for years previous to 1903 outstanding at 31st December, 1903 (Estimated Value)...		50 0 0	
		9,435 2 1	
Less Transferred to Building Fund ...		1,650 0 0	
			7,785 2 1

ROBERT KAYE GRAY,

President.

	£11,858 1 9

We beg to report that we have examined the above Balance Sheet and the Bankers' Certificates as to the Securities, and in our opinion the State- exhibit a true and correct view of the state of the affairs of the Institution at cost price. We hereby certify that all our requirements as Auditors have

ALLEN, BIGGS & CO.,
Chartered Accountants,
38, Parliament Street, S.W.

21st April, 1904.

31st DECEMBER, 1903.

Cr.

ASSETS.

		£ s. d.
By Cash :—		
At Bankers	3,171 10 0	
Petty Cash	83 13 11	
		3,255 3 11
,, Local Sections :—		
Cash in hands of Hon. Sec. Birmingham Section	4 12 6	
do. do. do. Glasgow Section ...	1 17 7	
do. do. do. Manchester Section ...	8 2 4	
do. do. do. Newcastle Section ...	4 13 1	
do. do. do. Leeds Section ...	10 4 1	
		29 9 7
,, Investments, General Fund :—		
£1,418 8 0 Midland Railway 2½% Consolidated Perpetual Preference Stock	£1,200 0 0	
918 3 2 India 3½ % Stock	973 17 10	
52 13 8 Great Indian Peninsula Railway "B" Annuity	1,239 17 9	
721 0 0 Madras Railway 5% Stock	1,114 14 0	
410 0 0 East Indian Railway 4½ % Debenture Stock...	586 1 7	
623 0 0 Great Western Railway 5 % Preference Stock	999 18 1	
		6,114 9 3
,, Subscriptions in Arrear (Estimated Value)		550 0 0
,, Sundry Debtors		256 17 0
,, Furniture :—		
As per last Balance Sheet	247 10 7	
Additions during 1903	143 9 0	
	390 19 7	
Less Depreciation (5 %)	19 11 0	
		371 8 7
,, Books, Pictures, &c., other than the Ronalds Library :—		
As per last Balance Sheet	1,300 9 7	
Additions during 1903	44 8 1	
	1,344 17 8	
Less Depreciation (5 %)	67 4 11	
		1,277 12 9
,, Stock of Vellum Diploma Forms		3 0 8
		£11,858 1 9

Statements of Account with the Books and Vouchers of the Institution, and
ments are correct, and the Balance Sheet is properly drawn up so as to
as shown by its books. The Securities have been included in the Accounts
been complied with.

F. C. DANVERS
SIDNEY SHARP } *Honorary Auditors.*

Professor S. P. THOMPSON: Before passing on to other business, I think it only right that I should call the attention of the members to a sentence in the Annual Report which otherwise might pass unnoticed, though I am sure it is one which they would not wish to overlook. It reads as follows, following on the statement as to the death of our lamented Secretary, Mr. McMillan, and the choice of his successor: "In the interval between the death of the late Secretary and the appointment of Mr. Lloyd, the President devoted a very considerable amount of his time to the affairs of the Institution, and it was largely owing to his unremitting attention that the continuity of the work of management went on without break or interruption." I venture to say, sir, that we should be glad if we might express in even a stronger form, the great indebtedness of the Council, and therefore of the Institution, to you for the wonderful way—and I can use no less adjective than that—the wonderful way in which you yourself devoted your time and energy to tiding over that very terrible gap. We owe you a great debt, a debt which is too inadequately acknowledged by this simple paragraph in the Report, and I feel sure I speak in the name of every member present when I venture to voice the expression of our indebtedness to you.

The PRESIDENT: I thank you very much, gentlemen, and I especially thank Dr. Thompson for the very kind way in which he has alluded to my services to the Institution. I also thank you for the manner in which you have received it. No one was more sorry than I that there was any cause for additional effort on my part, but it gives me great pleasure to learn that you, gentlemen, should think it worthy of note.

I have now to propose that the Statement of Accounts and Balance Sheet, of which copies were sent to the members with the notice convening the Annual General Meeting, be taken as read.

The proposal was unanimously agreed to.

The PRESIDENT: I have next to move that the Statement of Accounts and Balance Sheet for the year ending December 31, 1903, as presented, be received and adopted. I think in doing that I should read the Report and the Certificate of the Auditors. The Auditors say:—

"We beg to report that we have examined the above Balance Sheet, and the Bankers' Certificates as to Securities, and in our opinion the statements are correct, and the Balance Sheet is properly drawn up so as to exhibit a true and correct view of the statement of affairs of the Institution, as shown by its books. The securities have been included in the accounts at cost price. We hereby certify that all our requirements as Auditors have been complied with."

Perhaps while dealing with the accounts it should be mentioned that these are for the year ended December 31, 1903, and therefore do not include an account of the recent changes which have been made in acquiring the new building site in Tothill Street. I mention that in passing, because it might be wondered why no reference is made to this very matter in the Report. I now move that the accounts be adopted. The Hon. Treasurer has probably something to say about

them, and we shall be glad to have a few remarks from one who takes so much interest in this section of the Institution's affairs.

Mr. R. HAMMOND: It would hardly be fitting on the present occasion to go into the accounts in any detail, but the members will be pleased to note when they compare the items with the corresponding ones of 1902 that the subscriptions and entrance fees show an increase for the year of £2,222, whereas the expenditure shows only an increase of £136, leaving an excess for 1903 over 1902 of £2,086. (Hear hear.) It gives me much pleasure to second the resolution.

The PRESIDENT: Does any member desire to make any remarks or to ask any questions? If not, I would ask them kindly to signify in the usual way whether it is their wish that the accounts be approved and adopted.

The proposal to approve and adopt the accounts was unanimously agreed to.

The PRESIDENT then asked Mr. Swinton to propose the resolution placed in his hands.

Mr. A. A. CAMPBELL SWINTON: I beg to move that a vote of thanks be tendered to the Institution of Civil Engineers. As you all know, for many years past we have held our meetings at the house of the Institution of Civil Engineers in Great George Street, and the free use of the rooms in that building is granted to us for the purpose. Though we have now obtained a site for a building of our own, many years must, I suppose, elapse before we can hope to meet in our own house. It is, of course, a great advantage to this Institution to be able to hold meetings in such a place as the Institution of Civil Engineers, and I have therefore much pleasure in proposing that the best thanks of this Institution be tendered to the President and Council of the Institution of Civil Engineers for the great privilege accorded to this Institution in being permitted to hold its evening meetings in their rooms.

Mr. R. HAMMOND: Mr. Swinton, in moving this resolution, has made allusion to the fact that we have acquired a site upon which it is possible that we may erect a building. I think I am expressing the feeling of the Council when I do not put it more strongly than that. It has been felt that we should not miss the opportunity of acquiring a site, but the Council have taken no steps whatever towards entering into the very large expenditure that would be incurred by putting up a building of our own. And that makes us all the more grateful to the Institution of Civil Engineers, who have in the most gracious manner, year after year, placed their rooms at our disposal. It gives me much pleasure to second this resolution.

The resolution was carried with acclamation.

Mr. H. E. HARRISON: Sir, your Treasurer has told you that although we are landlords in the sense that we have land, unfortunately we are still houseless, and we may even exhaust the hospitality of the Institution of Civil Engineers. When that happens, we seek the hospitality of the Society of Arts, who always most generously accord to us the use of their rooms. I have pleasure to propose a vote of thanks to the Society of Arts, and to move that the members of the Institution of Electrical Engineers hereby express their cordial thanks to the Society of Arts for

the great privilege of holding their evening meetings in the rooms of that Society.

The proposal was seconded by Mr. S. DOBSON, and was unanimously carried.

Mr. H. M. SAYERS: Mr. President, unofficial members of this Institution must, if they think about it at all, often feel grateful for the very smooth way in which the machinery of the Institution works. The announcements of meetings come, meetings are held, copies of the Journal and *Science Abstracts* are delivered punctually, and in the ordinary way we hear very little about the way in which it is all done. But of course we all know that in running a great Institution like ours, with its many and varied branches, interests, and activities, a large amount of work is involved. And we also know that a very large share of that work devolves upon the President and the Council. Those who have not been called upon to work in that way do not perhaps adequately realise the sacrifice of time and the amount of energy and conscientious thought that is involved in carrying out work of this kind. But those who have tried it, and know something about it, are aware that the smooth and noiseless running of the organisation is the best testimony to the thoroughness with which that work is done. Therefore we have the very best reason for thanking the gentlemen who gratuitously, and at a very considerable sacrifice of their time, take upon themselves the burden of carrying out the aims of the Institution by which we all benefit. I have very great pleasure in proposing a vote of thanks to the President and Council for what they have done during the past twelve months. There have been special circumstances during the past year which have probably increased very considerably the work thrown upon both the President and the Council. The Telegraph Conference called for a certain display of hospitality, and we well remember the magnificent concert which was organised in the name of the Institution, but I fancy at very little cost to the Institution itself, although at the cost of a good deal of trouble and time on the part of the President and some other members. That was an exceedingly fine demonstration of hospitality given in our name, and, at any rate, we must thank those who organised it for the trouble they took. The death of Mr. McMillan necessarily put a very considerable amount of trouble upon the Council. Professor Silvanus Thompson has already mentioned the work done by the President, and has expressed what we all feel towards him for having stepped into the breach, and added to his already onerous work that of the detailed organisation generally carried on by the Secretary. We know Mr. McMillan worked very hard, and over-worked himself, and that the President should have taken up that work which over-worked Mr. McMillan, and done it in addition to his own, speaks volumes for his energy and vitality, and also for his devotion to the interests of the Institution. That is a very special reason, I think, for giving a hearty vote of thanks both to the President and the Council this year. Members, I think, may also consider that they have been provided with an exceedingly good programme during the past session. I do not remember a session which has been marked by a better selection of papers, and by a better

variety. They were nearly all good, practical papers, leading to interesting discussions, and the pronouncement of a variety of opinions. The discussion is, after all, the best test of the suitability of the paper, except when the paper is a record of some new work done. We have had both of these this session, and therefore we have to thank the Council for the selection they have given us. I am not quite sure whether the Council in London has anything to do with the selection of papers read before the Local Sections; but I think we must all recognise that whoever has selected those papers has done so with a very great sense of appropriateness, and I venture to say that the addition to the Journal of the papers read at Local Sections forms an exceedingly valuable part of our proceedings, and incidentally justifies the advance made in that direction. I have therefore great pleasure in moving that the best thanks of the Institution be, and hereby are, tendered to the President and Council for their services rendered during the past year.

Mr. R. J. WALLIS-JONES: I have very great pleasure in seconding the proposal put forward by Mr. Sayers, that the best thanks of the Institution be tendered to the President and Council for their services in the past year.

The vote of thanks was carried with enthusiasm.

The PRESIDENT then thanked the members present for the kind manner in which they had spoken of the work done by the President and Council.

Mr. J. E. KINGSBURY: I have pleasure in moving that the thanks of the Institution be given to the Local Honorary Secretaries and Treasurers for their services during the past year. I am very glad to hear Mr. Sayers' remarks showing appreciation of the work done in Local Sections. I think we all appreciate the manner in which the Local Sections are extending the objects of the Institution, and the admirable way in which they do it. We have realised, as the President remarked in his inaugural address, that large centres of activity in electrical work are being developed in the provinces and abroad; and I think there cannot be any doubt that in the future the growth of the Institution will largely result from the admirable work of the Local Sections. That work is carried on, of course, by officers, and a considerable amount of trouble and time is devoted by them to the work of the Sections. Of course the Treasurer occupies a position of considerable responsibility, and he is very much entitled to our thanks for the practical results achieved. But the Hon. Secretary, if I am to make any distinction at all, is entitled to our special thanks, for upon him devolves largely the work of obtaining papers and of carrying the discussions to a practical issue. I have only recently had an opportunity of seeing the amount of work which falls upon the Local Secretaries, and I am sure you will join with me in giving a hearty vote of thanks to the Local Secretaries and Local Treasurers.

The vote of thanks having been seconded by Mr. H. M. SAYERS, it was carried unanimously.

Mr. R. J. WALLIS-JONES: I have very much pleasure in rising to propose that the thanks of the Institution be accorded to Mr. Robert

Hammond for his kind services rendered during the past twelve months in connection with his office of Honorary Treasurer.

Mr. L. GASTER: I have much pleasure in seconding this vote of thanks to our popular Hon. Treasurer, Mr. Hammond. I trust that the Institution may long continue to avail itself of his kind services in the capacity of Hon. Treasurer, an office which he has now so long filled with conspicuous ability.

The vote of thanks was carried with enthusiasm.

Mr. HAMMOND: Mr. Chairman and Gentlemen, I have to express my very great appreciation of your very kind vote of thanks. I may say, with regard to the accounts, that it always has been a very great pleasure to me to be entrusted by you with the responsibility for them. There is one matter which lately has somewhat increased my work, and will, I trust, still further increase it, and that is the payments by members towards the expenses of the American visit. I trust that in that direction you will have no mercy upon the Hon. Treasurer, and that, in view of what is before you, you will use his services to the full. I thank you very much for the kind expression of your regard.

Mr. J. S. HIGHFIELD: I have great pleasure in proposing that the thanks of the Institution be given to Mr. F. C. Danvers and Mr. Sidney Sharp for their kind services as Honorary Auditors during the past year, and for the able way in which they have looked after our affairs.

The vote of thanks was seconded by Mr. R. J. WALLIS-JONES, and was carried unanimously.

Mr. B. DRAKE: I have pleasure in proposing that the thanks of the Institution be tendered to Messrs. Wilson, Bristows, and Carpmael for their kind services as Honorary Solicitors during the past year. With the rapid increase in membership there must be a corresponding increase of work for all departments, and this especially applies to our Honorary Solicitors, who have done a vast amount of work for which they have received no remuneration. I feel sure, therefore, you will wish to accord to them your very best thanks for the services they have so rendered.

Mr. W. H. PATCHELL: It gives me great pleasure to second that proposal, especially in view of the fact that, as Mr. Harrison has said, we have been negotiating for the purchase of a site this year, which naturally has thrown an immense amount of work on the solicitors. This all has to be checked very carefully, and solicitors as a rule are very expensive. We ought, therefore, to take very good care of our Honorary Solicitors. I have much pleasure in seconding the resolution.

The vote of thanks was accordingly unanimously passed.

The PRESIDENT: I have now to announce that the candidates balloted for on the two lists are certified as duly elected.

Member.

Hugh MacLellan Southgate.

Associate Members.

Richard Ley Alkin.
William Allan.
Percy John Barnes.
William Higginbotham.
Francis Madison Long.
John Edward Mellor.
William Reginald Potter.
Alexander Rothert.
Rupert Stanley.
David Stewart Strang.
Daniel John Lambert C. Westenberg.
Ernest James Wells.
Arthur Williamson.
Samuel Wilson.

Associates.

Lionel Shuttlewood Aldridge.
Allan Charles Campbell.
James Gifford Clack.
Harry Upton Collins.
Charles Brook Crawshaw.
George Edward Gittins.
Thomas Benson Heaviside.
John Stephens Just.
Frank MacCallum.
Frank Macey.
John Donald Mackenzie.
Ernest Robert Mahood.
John Lynn Marr.
Joseph G. Oliveri.
Arthur John Rayment.
Arthur Taylor.
Francis Douglas Watson.
George Scovell Whitmore.
Charles Wyatt.

Students.

William John Adcock Anderson.
Herbert Blades.
Arthur Philip Chalkley.
Evelyn Coad.
James Lewis Cook.
Herbert Robert Stanley Dean.
Edwin Gaskill.
John Gibson.
Wilfrid Hardy.
Edward C. Harris.
Kenneth George Stacy Hatfield.
Benjamin Bertrand Hawthorn.
Octavius Haughton Heard.
Bernard Theodore Hempel.
Frederick William Innes.
Leonard Kingwill Job.
Edward Horace Johnson.
Percival Legg.
John Frederic Linden.
Charles Henry Martin.
David O'Donaghue.
Ernest Henry Orton.
Leonard Anstice Pavitt.
Kashi Ram Puri.
Walter Riches.
James Rodgers.
Eliot Tarlton.
Joseph Stanley Westerdale.
John Percival Wilson.

The PRESIDENT: I have further to announce the result of the election of the new Council and Honorary Officers for the year 1904–5. According to the Articles of Association, as no candidates other than those nominated by Council have been put forward, the list stands as it has been circulated among you :—

President.

ROBERT KAYE GRAY.

The Past Presidents.

The Chairmen of Local Sections.

Vice-Presidents.

Dr. J. A. FLEMING, F.R.S.	W. M. MORDEY.
J. E. KINGSBURY.	W. H. PATCHELL.

Members of Council.

Sir J. WOLFE BARRY, K.C.B., F.R.S.	Dr. R. T. GLAZEBROOK, F.R.S.
T. O. CALLENDER.	F. E. GRIPPER.
S. DOBSON.	J. S. HIGHFIELD.
B. DRAKE.	H. HIRST.
S. Z. DE FERRANTI.	G. MARCONI.
JOHN GAVEY, C.B.	C. H. MERZ.
FRANK GILL.	C. P. SPARKS.
	A. A. CAMPBELL SWINTON.

Associate Members of Council.

T. MATHER, F.R.S.	SYDNEY MORSE.

A. J. WALTER.

Honorary Treasurer.

R. HAMMOND.

Honorary Auditors.

FREDERICK C. DANVERS.	SIDNEY SHARP.

Honorary Solicitors.

Messrs. WILSON, BRISTOWS, and CARPMAEL.

NOTE.—Mr. Alexander Siemens will assume office as President at the first Ordinary General Meeting of the Session 1904–5.

There is one note at the bottom of the list to which attention should be drawn, and which is put there more as an explanatory note than anything else, because since the passing of the Resolutions at the Special General Meeting immediately preceding this I am in a position to vacate one of two duties which I have to perform at present. I propose at the Council Meeting, which will be held immediately this meeting is concluded, to tender my resignation as President Elect, so that our worthy Past President, Mr. Alexander Siemens, may be elected to that post in my stead. I have now to thank you for your attendance to-day, and to declare that the business of the Annual General Meeting is terminated.

OBITUARY NOTICES.

JAMES ALFRED BRIGGS, died on November 21, 1903, at the comparatively early age of 59. He was a capable electrician and, in the course of his career, did a good deal of original work. During the seventies he invented, but did not patent, the "split-battery" method of duplex working, which practically doubled the carrying capacity of the lines and was adopted by the Indian Telegraph Department. For this special service he received the thanks of the Director-General. Somewhat later, he was associated with Dr. Muirhead in bringing out a patent for a system of Quadruplex Telegraphy, which was subsequently adopted and worked in the United States. Other patents of Mr. Briggs's dealt with "Improvements with Electrical Circuits" (conjointly with Mr. F. Kinsman); "Improvements in the Production of the Electric Light," and "Improvements in Dynamos." For a period of years he was Superintendent of the Indian Government Telegraphs, and the exigencies of the service took him to some of the least salubrious districts, on which account his health suffered severely. Before finally leaving India, he was attacked by a most dangerous illness, from the effects of which he never recovered sufficiently to complete the brilliant career which appeared open to him. He was elected a Member of this Institution in 1875. W. D.

A. LE NEVE FOSTER died very suddenly on June 7, 1904, at his residence in London. In his early career he was associated with the Indian Rubber, Gutta-Percha, and Telegraph Works Company, and on leaving their service he accepted an appointment with the firm of Davis & Timmins at a time when the electrical industry was comparatively in its infancy. As managing director of the latter firm, and in other capacities as an electrical engineer, Mr. Le Neve Foster was frequently in touch with the electrical profession generally. He was elected an Associate in 1873, and was transferred to the class of Members in 1876.

JAMES HOOKEY, who died on the 14th of November, 1903, was born at Bristol in 1839, and was educated at Bath, at which place he entered the service of the Electric and International Telegraph Company in 1855. His ability soon marked him out for advancement, and in 1861, after acting as Telegraph Clerk to the Queen, he was appointed Engineering Inspector of the Company's West Midland Section. In 1862 he was transferred to the office of the then Engineer-in-Chief, Mr. C. F. Varley, serving later under his successor, Mr. R. S. Culley. On the acquisition of the telegraphs by the State, Mr. Hookey was offered the position of Superintendent of the Telegraph System on one of the great railways, but he decided to enter the Post Office under his old chief, Mr. R. S. Culley.

He was appointed Principal Technical Officer in 1882, and, on the death of Mr. E. Graves, he was promoted to the position of Assistant Engineer-in-Chief. On the retirement of Sir William Preece in 1899,

Mr. Hookey succeeded him as Engineer-in-Chief. He retired on the 31st of March, 1902.

His grasp of detail was remarkable, and being possessed of a very retentive memory, he acquired a store of information on subjects connected with telegraphy which he used to the great advantage of the public service. One of his strongest points was the combination of financial skill with high technical qualifications; but he excelled also in the management of men; and he will always be remembered for his uniform kindness of heart which won for him the warm regard of those who knew him. Mr. Hookey was elected an Associate in 1872, and was transferred to the class of Members in 1886. J. G.

J. C. KIDD died at his residence at Cardonald, near Glasgow, on October 22, 1903, at the age of 60. Throughout the greater part of his career he was engaged in the Government Telegraph Workshops at Alipore, near Calcutta, having gone out to India in 1869, at a time when telegraph construction in that country was still in its infancy. It was chiefly due to his energy and talent for organisation that the Government works developed from the small beginnings which he found at the time he first joined until they reached their present capacity. When he left the service the works were employing some 750 men, and were capable of turning out all the ordinary telegraph instruments used in India and a large proportion of the iron poles and fittings used on the lines. It was a good life's work alone to have trained up so large a number of natives to become the efficient workmen they were at the time he left. For 32 years he laboured ungrudgingly in the service of the Department, and his health being then much shattered by the trying climate, he at length in May, 1901, sought retirement in his native country of Scotland. His loss to the works was greatly felt by his associates and by the men who had worked under him. It was the writer's privilege to have been associated with him in his work at intervals for 18 years, and he was many times witness of his remarkable capacity for managing the native workmen, by whom he was held in high respect and esteem.

He was elected an Associate of the Institution of Electrical Engineers in 1880, and was transferred to Membership in 1899.

WALTER GEORGE McMILLAN, who had been Secretary of this Institution since 1897, died very suddenly on January 31, 1904. Born on January 3, 1861, he passed first through King's College School, and subsequently entered King's College, London. Here he became a prominent student in the Chemical Department, and as the result of a research on the effect of the electric spark on mixtures of oxygen and nitrogen, he was awarded the Daniell Scholarship in 1880. His student's course was followed by a year's work in the office of an accountant, which afforded a good opportunity for gaining some experience in business methods, after which he returned to scientific work and joined the staff of King's College, assisting Professor Thomson in his lectures at Queen's College, and becoming Demonstrator of

Metallurgy at King's College. He took a marked interest in students' affairs, being President of the Students' Scientific Society, and was, indeed, an excellent organiser of any of their societies having pure and applied science as an object. But his energies were by no means restricted to the College, for he did a large amount of most valuable charitable work which was only known to his most intimate friends. He also held scientific evenings for poor boys, and gave lectures on applied science to working men, following these up with competitions.

In 1888 Mr. McMillan was appointed by the Indian Government for five years as chemist and metallurgist to the Cossipore Ordnance Factories, near Calcutta. While in India he acted as Examiner in Chemistry to the University of Calcutta, and was also appointed a Municipal Commissioner of Cossipore-Chitpore, a manufacturing suburb of Calcutta.

Upon his return from India, Mr. McMillan was appointed to a Lectureship in Metallurgy at Mason's College, Birmingham, and about this time he turned his attention more to literature. He had already written with Professor Huntington the book on "Metals" in Longman's "Text Books of Science" Series, but having since that time paid attention to electrical methods, he wrote in 1890 a "Treatise on Electro-Metallurgy"; and in 1897 he translated Dr. Borchers' book on "Elektro-Metallurgie," adding notes thereto and calling it "Electric Smelting and Refining," a fresh edition of which was in the press at the time of his death. He also contributed the articles on Electro-Chemistry and Electro-Metallurgy in the recently issued supplement of the "Encyclopædia Britannica." He was an abstractor of the Society of Chemical Industry, a Fellow of the Chemical Society and of the Institute of Chemistry, a member of the Institution of Mining and Metallurgy; and in 1897 he was elected Vice-President of the South Staffordshire Institute of Iron and Steel Works Managers.

So far Mr. McMillan was well known in the chemical world; but in 1897 he made a complete change in his life by accepting the post of Secretary of this Institution, undertaking also the editing of the Journal. The membership of the Institution was then less than 3,000, but since that time it has increased to over 5,000, and the work has quadrupled. There have also been many important changes, such as the formation of the class of Associate Members, the inauguration of Local Sections, the introduction of foreign visits, the formation of Sectional Committees (a suggestion of his own), and the first effective steps in securing a home of its own for the Institution. These were apparent to all. But it was, of course, to those who saw the inner working of the Institution that the value of Mr. McMillan's work was most apparent. There never seemed too much work to be done. Even at the busiest times he was at the disposal of every one, always tactful, always courteous, and thus he became as much a personal friend as the representative of the Institution. No detail was too small for his attention. If a difficult question had to be decided, every possible kind of information had been carefully prepared to aid the solution. Whatever was undertaken, whether a dinner, a concert, or a foreign visit, every detail was thought out before the event, and

everything was sure to pass off with the greatest smoothness. The value of such work, and the unobtrusive way in which it was carried out, were recognised on more than one occasion, either by the members themselves or by the Council. In one respect this attention to detail was Mr. McMillan's one fault, for it made it almost impossible for the Council to relieve him of work as they wished; his extreme sense of duty made him delegate as little as possible to others, and he was always ready to take up more.

In 1903 Mr. McMillan was pressed to take a longer holiday than usual, from which he returned to the additional work of gathering up the threads of *Science Abstracts*, the general management of which had been added to his other duties. He was devoting much of his untiring energy to this subject, when illness compelled him to put his work aside. He was found to be suffering from pleurisy, but no great anxiety was felt, as he was making satisfactory progress. Indeed, the latest reports were reassuring in every way, for it appeared that the convalescent stage had been reached, and it was expected that he would be about again, if not at work, in a very few days. But a sudden and unexpected attack of heart failure proved fatal, and he passed away on Sunday, January 31, 1904, leaving a widow and two children. He was elected an Associate of the Institution in 1897. W. R. C.

FREDERICO PESCETTO died at Cornigliano Ligure on November 7, 1903, at the age of 56. After following the Course of Studies at the Military Academy in Turin, he entered the Corps of Engineers, in which he rose to the rank of Colonel. He paid particular attention to the subject of Electrotechnics, and when he attained the rank of Captain, he obtained the permission of his Government to complete his training at the Institut Electrotechnique Montefiore, at Liège. Here he was at the head of his class, and left with a *diplôme d'honneur*. Subsequently he gave lectures on Electrotechnics to the Artillery and Engineer officers of the Italian Army. His competence in electrical matters was universally acknowledged, and the War Department having, at his request, placed him on the Auxiliary List, he was entrusted with the erection and management of the works known as "Stabilimento Elettrotecnico Gio. Ansaldo & Co.," of which he was Manager at the time of his death. He was a member of the Board of Directors of the Industrial Museum in Turin, where he had formerly attended the Electrotechnical lectures of Galileo Ferraris, whom he held in great esteem, and with whom he was bound by ties of mutual sympathy and friendship. He was of a cheerful disposition and his kind and courteous manner towards all with whom he came into contact obtained for him a large circle of friends both at home and abroad; and in him science lost one of its most gifted interpreters. He was elected a Foreign Member in 1900, and in 1903 he was transferred to the class of Members. G. S.

ROBERT CORNELIUS QUIN, who died on January 11, 1904, was born in London in 1865. He received his early education at a public elementary school, and commenced his engineering training by

entering the office of Mr. J. N. Shoolbred, whom he left to join the staff of the Bradford Corporation Electricity Works, the first Municipal Electricity Supply Station in England. He resigned his position at Bradford in order to take up a position under the Brighton Corporation, and remained there for about six years. In 1896 he was appointed Borough Electrical Engineer to the Corporation of Blackpool, and in 1897 this appointment was made to include that of Borough Electrical and Tramway Engineer. During the time Mr. Quin was at Blackpool he converted the conduit system of tramways in operation there to the overhead system, and further carried out numerous and large extensions to the Electricity Works. During the last three years of his tenure of office at Blackpool, he, under an agreement with the Corporation, also acted as Consulting Engineer to various municipalities and private companies, and it was owing to his growing practice in this direction that, in order to devote himself entirely to consulting work, he resigned his appointment in 1902, when, in conjunction with Mr. J. W. Speight, he founded the business of Messrs. Quin & Speight. At the time of his death, which was the result of a sad accident by drowning off the north coast of Ireland, he was the senior partner of this firm. He was elected an Associate of this Institution in 1896, and was transferred to the class of Members in 1898. J. W. S.

ERNEST THOMPSON died on January 9, 1904, at the early age of 36. He was taken ill in October, 1902, and was ordered by his medical advisers to take a sea voyage. This he did by taking a trip round the world, and it was hoped that the voyage would benefit him permanently, but he had only been at work for three months when he had a relapse. After following the course of Electrical Engineering at the Finsbury Technical College under Professor S. P. Thompson, he became a pupil at the Immisch Works, Chalk Farm, and, subsequently, acquired further experience in the works of Messrs. Siemens Bros. & Co. and at the Brush Electrical Engineering Co. In 1893 he became an Assistant in the works of Messrs. Nalder Bros. & Co., and took charge of the test-room of the voltmeter and meter department. When the business of this firm was divided in 1896, he went into partnership with Mr. F. H. Nalder, and formed with him the firm of Nalder Bros. & Thompson, of which he was an active partner at the time of his death. His restless energy and the thorough and conscientious way in which he carried out his work impressed all who knew him. He was elected an Associate in 1890, and was transferred to the class of Associate Members in 1899. F. H. N.

CHARLES ASPULL WELLS died suddenly at Lewes on April 6, 1904, at the age of 78. The same town was also his birthplace and residence throughout his life. After completing his education at school he entered, in 1842, the service of Mr. H. A. Thompson, of the Etna Ironworks, where he was at first engaged partly in the workshops and partly in the office. Six years later the firm exhibited on a large scale at the Royal Agricultural Society's Show at Lewes, and a catalogue for the press was prepared by Mr. Wells.

He also had the advantage on this occasion of making the acquaintance of Mr. Fothergill Cook, joint inventor of the electric telegraph. About this time he took an active part in the organisation of classes at the Mechanics' Institute, and in 1853 he gave his first public lecture at the Institute, continuing for many years to lecture on electricity, chemistry, and the arts. In 1858 he became manager of Mr. Thompson's works, and on the death of the latter he succeeded to the business. To Mr. Wells belongs the honour of the introduction of the electric light into Lewes.

For many years he was prominently associated with the public affairs of his native town, and on the incorporation of the borough in 1881 he was elected a member of the Town Council, an office which he continued to hold until 1888, when he retired. He was elected an Associate of the Institution of Electrical Engineers in 1889, and was transferred to the class of Associate Members in 1902.

THOMAS J. WILMOT, superintendent of the Commercial Cable Company's station at Waterville, Ireland, died April 12, after an illness of three weeks.

Born in London, in September, 1851, Mr. Wilmot commenced his telegraph career by entering the service of the Electric and International Telegraph Company in 1866. In 1874 he entered the service of the Direct United States Cable Company, and in 1884 that of the Commercial Cable Company, in which year he was appointed superintendent of the Boston office of the latter company. In 1885 he was appointed superintendent of the Commercial Company's main cable station at Waterville, Ireland, which position he held for nineteen years with great credit to himself and satisfaction to his employers.

Mr. Wilmot was well known in cable circles. He perfected a system of repeating between submarine cables and land lines, but perhaps his most notable achievement was the application of his automatic transmitter to long submarine cables. Many experiments had preceded Mr. Wilmot's in this direction, but they left the proposition discredited in the eyes of cable men who had contended that the human touch was essential to successful long cable signalling. Mr. Wilmot was, however, convinced that this was not so, and he had the satisfaction of demonstrating the soundness of his opinions by producing a thoroughly practical instrument which improved the signals and increased the speed. He was elected an Associate of this Institution in 1876, and was transferred to the class of Members in 1886.

RUSSELL OSWALD WRIGHT died on April 10, 1904, at the age of 39. Educated at St. Saviour's School, London, he was, in 1880, apprenticed to Messrs. Elmore, Ltd. who, on the expiration of his apprenticeship, placed him in charge of the electrotyping department. While in the employ of this firm he obtained considerable experience in the construction of dynamos for depositing purposes, and he also had charge of the early experiments in the manufacture, by electrolysis, of the copper plates for the map printing of the Ordnance

Survey Office at Southampton. In 1896 he fitted up works at Blackburn, where he remained for some years, and carried out several important installations. Subsequently he joined the staff of the Fine Cotton Spinners' and Doublers' Association as Chief Electrical Engineer, and was still in their employ at the time of his death. He was elected an Associate Member of the Institution in 1902.

REFERENCES TO PAPERS READ BEFORE LOCAL SECTIONS OF THE INSTITUTION, AND PUBLISHED, IN FULL OR IN ABSTRACT, IN THE TECHNICAL PRESS, BUT NOT YET ORDERED TO BE PRINTED IN THE JOURNAL OF THE INSTITUTION.

BIRMINGHAM LOCAL SECTION.

"ENERGY DISTRIBUTION TO SUB-STATIONS," by C. ALFRED SMITH, B.Sc., Associate.

Electrical Review, Vol. **54,** p. 372, March 4, 1904.
Electrician, Vol. **52,** p. 950, April 1, 1904.

"MOTOR STARTING SWITCHES AND RESISTANCES," by F. C. HUNT, Associate Member.

Electrician, Vol. **53,** p. 526, July 15, 1904.

DUBLIN LOCAL SECTION.

"STATIONARY ELECTRIC WAVES," by the VERY REV. MONSIGNOR MOLLOY, D.D., Member.

Electrician, Vol. **52,** p. 320, December 18, 1903.
Electrical Engineer, Vol. **33,** p. 915, December 18, 1903.

"THE SUPPLY OF ELECTRICITY TO SMALL TOWNS," by T. TOMLINSON.

Electrical Review, Vol. **54,** p. 564, April 1, 1904.
Electrical Engineer, Vol. **33,** p. 416, March 11, 1904.

"NOTES ON HARMONICS IN THREE-PHASE WORKING," by W. TATLOW, Associate Member.

Electrical Engineer, Vol. **33,** p. 176, January 29, 1904.

GLASGOW LOCAL SECTION.

"SHOULD ELECTRIC SUPPLY UNDERTAKINGS ADVANCE MOTORS ON THE HIRE OR HIRE-PURCHASE SYSTEMS?" by S. E. BRITTON, Associate Member.

Electrical Review, Vol. **54,** p. 408, March 11, 1904.
Scottish Electrician, Vol. **4,** p. 48, March, 1904.

"ELECTRIC HAULING MACHINERY FOR COLLIERIES AND ALLIED PURPOSES," by M. GEORGI, Associate Member.

Electrical Review, Vol. **54**, p. 681, April 22, 1904.
Scottish Electrician, Vol. **4,** p. 51, March, 1904.

"COAL-CUTTING MACHINERY," by SAM MAVOR, Member.

Electrical Review, Vol. **54,** p. 682, April 22, 1904.

"CORPORATION TELEPHONES," by A. R. BENNETT, Member.

Electrical Times, Vol. **25,** p. 583, April 21, 1904.
Scottish Electrician, Vol. **4,** p. 94, May, 1904.

LEEDS LOCAL SECTION.

"SOME NOTES ON STEAM TURBO-ELECTRIC GENERATING PLANTS," by G. WILKINSON, Member.

Electrical Times, Vol. **24,** p. 660, November 5, 1903.
Electrical Review, Vol. **53,** p. 691, October 30, 1903.
Electrician, Vol. **52,** p. 19, October 23, 1903.
Electrical Engineer, Vol. **32,** p. 656, October 30, 1903.

"DESTRUCTOR AND ELECTRICITY STATIONS IN SMALL TOWNS," by S. D. SCHOFIELD, Associate Member.
Electrical Times, Vol. **24,** p. 856, December 10, 1903.
Electrician, Vol. **52,** p. 178, November 20, 1903.

"METHODS FOR CHARGING FOR ELECTRICAL ENERGY," by E. H. CRAPPER, Member.
Electrician, Vol. **52,** p. 330, December 18, 1903.
Electrical Engineer, Vol. **33,** p. 117, January 15, 1904.

"ALTERNATORS IN PARALLEL," by H. BOHLE, Associate Member.
Electrical Times, Vol. **25**, p. 122, January 28, 1904.
Electrical Review, Vol. **54,** p. 240, February 5, 1904.
Electrician, Vol. **52,** p. 784, March 4, 1904.

MANCHESTER LOCAL SECTION.

"COAL CONSUMPTION IN CENTRAL STATIONS," by A. S. GILES, Member.
Electrical Times, Vol. **25,** p. 124, January 28, 1904.
Electrical Review, Vol. **54,** p. 241, February 5, 1904.
Electrician, Vol. **52,** p. 530, January 22, 1904.

"MANCHESTER TRAMWAYS EQUIPMENT--LINE AND ROLLING STOCK," by J. M. McELROY.
Electrical Times, Vol. **25,** p. 285, February 25, 1904.
Electrical Review, Vol. **54,** p. 327, February 26, 1904.

NEWCASTLE LOCAL SECTION.

"REGULATING IMPEDANCE COILS," by C. F. PROCTOR, Member.
Electrical Review, Vol. **54,** p. 971, June 10, 1904.
Electrician, Vol. **52,** p. 997, April 8, 1904.
Electrical Engineer, Vol. **33,** p. 442, March 11, 1904.

"A FEW NOTES ON THE STEAM TURBINE," by THE HON. G. L. PARSONS, Associate Member.
Electrical Review, Vol. **54,** p. 605, April 8, 1904.
Electrician, Vol. **52,** p. 996, April 8, 1904.
Electrical Engineer, Vol. **33,** p. 571, April 8, 1904.

"THE TUITION OF ELECTRICAL ENGINEERS," by J. PIGG, Associate.
Electrical Engineer, Vol. **33,** p. 853, June 3, 1904.

NOTE.

The Institution is indebted to the Editors of various Technical Papers for the use of some of the blocks employed in this volume of the Journal.

INDEX TO VOL. 33.

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EXPLANATION OF ABBREVIATIONS.

[P] signifies that the reference against which it is placed indicates the general title or subject of a Paper, read either in London or at a Local Section, or published as an Original Communication.

[*p*] signifies that the reference is to a subject incidentally introduced into a paper, and not necessarily indicated by the title.

[D] signifies that the reference is to remarks made in a Discussion upon a paper, of which the general title or subject is quoted.

[*d*] signifies that the reference is to remarks incidentally introduced into a discussion on a paper, of which the title differs from that given in the reference.

[*Ref.*] indicates that, on the page quoted, a reference is given to the place of publication in the Technical Press of a Paper read at a Local Section, and not yet printed in this Journal.

[Demonstr.] indicates that the reference is to a Demonstration of Apparatus, not accompanied by a Paper.

[Birm. L.S.] signifies that the paper referred to was read at a meeting of the Birmingham Local Section.

Note.—The lists of speakers in the Discussion upon any Paper are not quoted in the Index. They are, however, given in the Table of Contents at the beginning of the volume, and are readily found by ascertaining the page in the Journal from the entry in the Alphabetical Index, and then referring back to the corresponding portion of the Table of Contents, which is arranged serially in the order of the pages of the Journal.

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